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THE LATE QUATERNARY LACUSTRINE RECORD FROM THE UPPER
CATARACT BROOK VALLEY, YOHO NATIONAL PARK, BRITISH COLUMBIA

by

(C)
Mel A. Reasoner

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH IN
PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF

Master of Science

Department of Geology

Edmonton, Alberta

Spring, 1988

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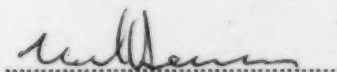
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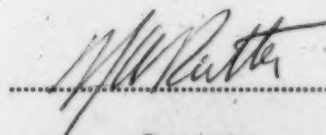
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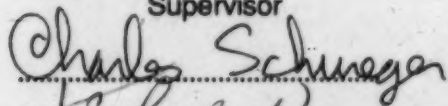
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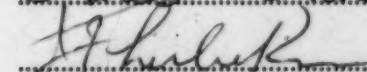
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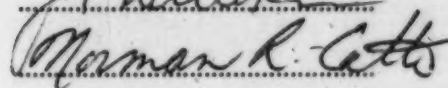
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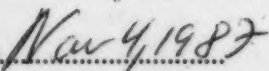

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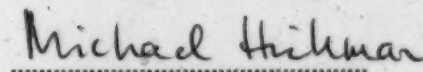
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ABSTRACT

Three lakes in the upper Cataract Brook Valley - Lake O'Hara, Mary Lake, and Opabin Lake - are situated directly adjacent to a high section of the Continental Divide in the central Canadian Rocky Mountains. A total of 30 cores were recovered from the lakes using a lightweight percussion coring system designed for winter use in remote areas. The cores show a consistent stratigraphy comprising tephra bearing gyttja and underlying clastic lacustrine sediments. The identification of Bridge River (2350 years BP) and Mazama (6800 years BP) tephras was confirmed by electron microprobe analysis of the constituent glass shards. Radiocarbon dates obtained from conifer needles (extracted from lowermost sediments) indicate that deglaciation had proceeded upvalley from the O'Hara basin prior to ca. 10,100 years BP. Highly variable sedimentation rates in the Lake O'Hara records suggest that the use of this data as a proxy record of upvalley glacial activity is inappropriate in Lake O'Hara, which is not directly fed from a glacial source. Higher total sedimentation rates in post - Bridge River Opabin Lake cores are related to climatic conditions associated with more extensive upvalley ice. Increasing downcore trends in the aspartic acid D/L ratios suggest that amino acid data from bulk gyttja samples may be used as a check for reworking in cases where chronostratigraphic markers are absent.

The post-glacial colonizing vegetation prior to ca. 10,100 years BP at Lake O'Hara and before ca. 8530 years BP at Opabin Lake was a shrub herb

community dominated by *Artemisia*, Gramineae and *Alnus*. Pioneering forests at both sites were composed of *Pinus* cf. *albicaulis/flexilis* and *Abies* with lesser abundances of *Picea* and *Pinus* cf. *contorta*. Timberline remained above the elevation of Opabin Lake for the period ca. 8500 years BP to ca. 3000 years BP in response to warmer climatic conditions associated with restricted glacial activity. Forest compositions resembling the modern subalpine *Picea-Abies* forest had developed by the end of this period. The period ca. 3000 years BP to present was marked by deteriorating climatic conditions associated with renewed glacial activity in the Opabin Cirque and declining timberlines to below the elevation of Opabin Lake.

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CHAPTER 1

INTRODUCTION

Investigations of the Late Quaternary palaeoenvironmental history of the Canadian Rocky Mountains began in earnest with the classical study of Heusser (1956). Since that time, a number of studies have focused on areas in the lower valleys and foothills (e.g., Kearney and Luckman 1987; Schweger 1985; MacDonald 1982; Ferguson 1978). In contrast, palaeoenvironmental records from alpine sites are limited to the Maligne Range (Luckman and Kearney 1986; Kearney and Luckman 1983a, 1981) and Wilcox Pass (Beaudoin 1987, 1986, 1984). Leonard (1987, 1986a, 1986b) and Kearney and Luckman (1983b) are the only workers who have provided Holocene records from sites located near the Continental Divide.

This study documents the latest Wisconsinan and Holocene lacustrine sedimentary records of Lake O'Hara and Opabin Lake in the upper Cataract Brook Valley of Yoho National Park, British Columbia. Opabin Lake and Lake O'Hara were selected for study to provide palaeoenvironmental information from alpine and subalpine settings respectively. The two lakes span the modern timberline ecotone and are situated near the Continental Divide in the central Canadian Rocky Mountains. The specific objectives of this study were: (1) to design a coring system that would be practical in remote alpine settings; (2) to establish the identities of tephras preserved in the recovered cores; (3) to obtain

limiting radiocarbon dates for deglaciation of the upper Cataract Brook Valley from basal organic material; (4) to evaluate the consistency of Holocene sedimentation rate data over the Lake O'Hara basin; (5) to assess the reliability of amino acid D/L ratios obtained from bulk gyttja samples of known age; and (6) to provide a record of Holocene palaeoenvironmental change for alpine and subalpine settings based on pollen and macrofossil records. The results of these objectives are presented and discussed in Chapters II through V, and are summarized in Chapter VI.

Chapter II describes the assembly and operation of a percussion core sampling system that was designed for winter use in remote areas. The system is inexpensive, lightweight and can be operated by one person in the field. A total of 30 cores were recovered from lakes in the upper Cataract Brook Valley using this system. Many of these cores contain sediments representing the entire Holocene record as well as the uppermost Late Wisconsinan sediments. These cores provided the basis for Late Quaternary records discussed in Chapters IV and V.

The tephrochronology of the Upper Cataract Brook Valley is defined in Chapter III. The Bridge River tephra (ca. 2350 years BP) and the Mazama tephra (ca. 6800 years BP) were identified in a core from Mary Lake which is situated adjacent to Lake O'Hara. Electron microprobe analyses of glass shards, as well as the determination of field characteristics, were employed to confirm the identities of the two tephtras. Also, the details of a modified electron microprobe

method for analyzing glass shards are presented. The identification of these tephras, in conjunction with radiocarbon dating, provided the chronologic control necessary for the evaluation of sedimentation rate variability and amino acid ratios (Chapter IV), and for the palaeoenvironmental reconstructions (Chapter V).

Chapter IV documents basal radiocarbon dates obtained from the cores and comments on their significance in terms of the deglaciation of the study area, as well as regional deglaciation. The basal dates impart considerable constraint on the timing of deglaciation in the Bow Valley because the lakes are situated in a source area for Bow Valley ice. The approximate rate of Late Wisconsinan deglaciation in the Bow Valley is based on the limiting dates from Lake O'Hara and estimated ice positions from locations downvalley. Chapter IV also documents the variability of Holocene sediment accumulation in the Lake O'Hara Basin, a factor that is often assumed to be constant in studies based on the recovery of single cores from lakes. Finally, downcore trends in amino acid D/L ratios from bulk gyttja samples of known age are documented and their chronologic significance is discussed.

Chapter V provides a Late Quaternary palaeoenvironmental reconstruction for the upper Cataract Brook Valley. Pollen and macrofossil records from Lake O'Hara and Opabin Lake register changes in local vegetation throughout the latest Wisconsinan and Holocene. Also, these records reflect the up and down-slope fluctuation of the climatically sensitive timberline ecotone over this period. Late Quaternary palaeoclimatic conditions are inferred from the

changing composition of vegetation surrounding the two lakes as well as from the fluctuating elevations of ancient timberlines.

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CHAPTER 2

AN INEXPENSIVE, LIGHTWEIGHT PERCUSSION CORE SAMPLING SYSTEM. †

† A version of Chapter 2 has been published. Reasoner, M. A. 1986.

Géographie physique et Quaternaire, vol. XL, no. 2, p. 217-219.

INTRODUCTION

Core sampling devices which are commonly employed for lacustrine settings are the Livingstone system (Livingstone, 1955) and its modifications (eg., Wright 1967; Patterson *et al.* 1978) or small, gravity impact coring devices (e.g., Phleger, 1951). The Livingstone system is expensive, requires two or more people for transportation and operation in remote areas, and is restricted for use in water depths of less than approximately 30 m. Gravity impact coring devices (drop corers), although unrestricted by water depth are limited in terms of penetration and core recovery. This is particularly true in remote locations where the transportation of heavy weights for these systems may be difficult. Furthermore, there is no guarantee that gravity coring systems with long core barrels will remain vertical during "free fall" into bottom sediments. The generally complex, cumbersome and expensive nature of existing coring systems has prompted the development of simple lightweight coring systems that are practical in remote settings, such as the percussion system designed for summer operation from small boats by Gilbert and Glew (1985) and the system described herein.

The percussion coring system described here is designed for winter operation, is simple and inexpensive, can be transported and operated by one person in the field, and is theoretically unrestricted by water depth. A prototype of the system was tested in March and April 1985. A total of 30 core samples, 140 to 257 cm in length, were singlehandedly recovered from four subalpine and

alpine lakes in Yoho National Park, British Columbia. The identification of accurately dated Bridge River and Mazama tephras in the recovered sediments (Reasoner and Healy 1986), and the recovery of up to 30 cm of "basal" diamicton, suggests that many of the core samples may represent the entire postglacial record. Although the system does not employ a piston, complete core recovery was ensured by the use of an effective core catcher. During testing, the system functioned without difficulties in shallow areas, as well as in water depths of over 40 m, which were the maximum encountered. Slight to moderate core disturbance in the form of downwarped beds along the core edges was observed in split core.

The major advantages of coring under winter conditions are (1) accurate core locations are easily obtained, (2) a boat is not required for a coring platform or for transportation, and (3) the stable platform provided by the ice pack can be utilized for core removal. Transportation of the coring system was carried out entirely on cross-country skis or snowshoes, however, a snowmobile was required to transport the estimated 320 kg of recovered core to the nearest road at the end of the field season.

DESCRIPTION AND ASSEMBLY

The coring system consists of three major components; the core barrel, the core head and the driver (Figure 1). Core barrels are 3 m lengths of thin-walled 7.6 cm inside diameter PVC pipe. The core barrels are fitted with

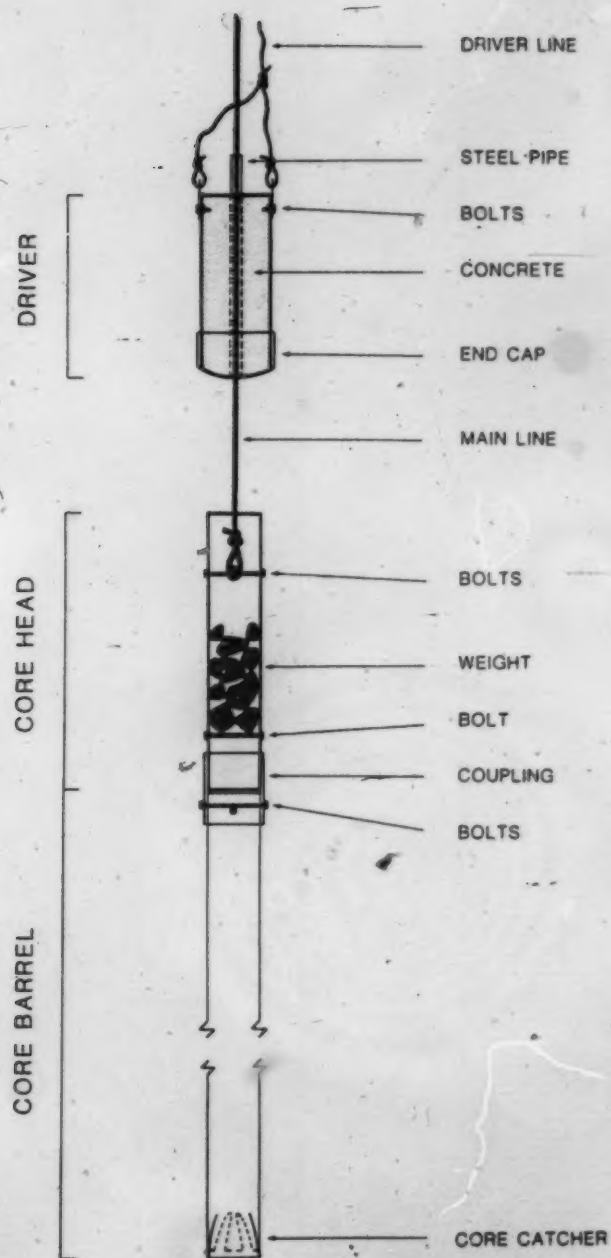


Figure 2-1. Schematic diagram of the coring system. The driver is raised and dropped approximately 2 m in order to drive in the core barrel. The driver is guided to the core head-core barrel assembly by the main line. See text for discussion of materials used in the construction of the system.

basket-type core catchers similar to those used in split-tube samplers. The core catcher described here consists of a ring of five fingers, each 10 cm long, cut from thin sheet metal. The rings are positioned inside the bottom ends of the core barrels with the finger pointing up and bent in slightly (Figure 1). The lower 1.5 cm of the core catcher rings are cut into short segments and bent over the outside of the core barrels. The core catchers are held in place by 3.2 mm pop rivets which are flattened with vice-grip pliers to reduce core disturbance. A similar inexpensive core catcher for plastic vibracore tubes is described by Reddering and Pinter (1985).

The core head is assembled from a 1 m length of ABS pipe (7.6 cm inside diameter) with a standard 7.6 cm coupling attached to the lower end with ABS glue (Figure 1). This attachment is reinforced with small bolts. The thicker-walled ABS pipe is used for the core head in order to withstand the impact of the driver. Two 1.3 cm bolts inserted at 90 degrees to each other, 12 cm below the top of the core head, provide a rope attachment that centres the main line. Weight may be added to the system as required by inserting cobbles in the core head. The core head and core barrels are joined with 6.4 mm bolts inserted in pre-drilled holes.

A 60 cm length of ABS pipe (10.2 cm inside diameter) fitted with a standard ABS end cap and filled with concrete is used as a driver (Figure 1). A 2.5 cm diameter steel pipe is set in the centre of the driver, and rope attachments are placed prior to pouring the concrete. By adding scrap iron to the concrete, the weight of the driver may be increased.

To ensure recovery, a high-strength 11 mm diameter perlon climbing rope is used for the main line to lower and raise the core head-core barrel assembly. A 6.4 mm diameter nylon rope is used to raise and drop the driver.

OPERATION

After a hole is made in the ice pack, the core barrel, core head and driver are lowered through the water column and allowed to settle slowly into the surficial bottom sediments. The driver is then raised and dropped approximately 2 m in order to drive in the core barrel. Maintaining tension on the main line is critical during the initial stage of the driving process to keep the system vertical until the core barrel is firmly set into the bottom sediments. As the driver is guided to the core head by the main line, sufficient tension (1-2 kg) is required to keep the main line taut during driving. Downward progress of the core barrel into the sediments during the driving process can be accurately monitored on the surface by attaching paper clips to the main line. Several hundred blows may be required for 3 m penetration. Several carabiners (snap links) are useful for line attachments and minimize the tying and untying of knots under cold and wet conditions.

In the initial stages of system testing, the core head-core barrel assembly was allowed to fall rapidly from a height of approximately 10 m above the lake bottom. This method of starting the core barrel was found to be undesirable as, on several occasions, the core head-core barrel assembly came to rest

horizontally on the bottom sediments. On these occasions, downward progress of the main line during driving was not observed and core samples were not recovered, which together could have been interpreted as an indication of hard bottom conditions. However, the appearance of conspicuous dents on the uppermost sidewall of the core head clearly demonstrated that the core head-core barrel assembly had been in a horizontal attitude during the driving process. Core samples were subsequently recovered from these locations when the system was slowly lowered into the sediments.

Once the driving process is completed, the driver is raised and removed from the main line. A pulley system is then set up on the ice surface to provide the mechanical advantage required for core removal. A tubular ice screw (a common piece of climbing equipment) is inserted into the ice pack 10 to 15 m from the hole. The main line is then threaded through pulleys attached to the ice screw and to a prusik knot (Ferber, 1974) tied to the main line near the hole (Figure 2). Utilizing the mechanical advantage of the pulley system, the core head-core barrel assembly is removed from the sediments by hauling on the main line. On several occasions, additional pulleys were required at the prusik knot and ice screw in order to increase the mechanical advantage for removal. Due to the forces involved, recovery on these occasions would have probably been difficult from a small boat. Once the core barrel is clear of the bottom sediments, the system can be raised through the water column by hand.

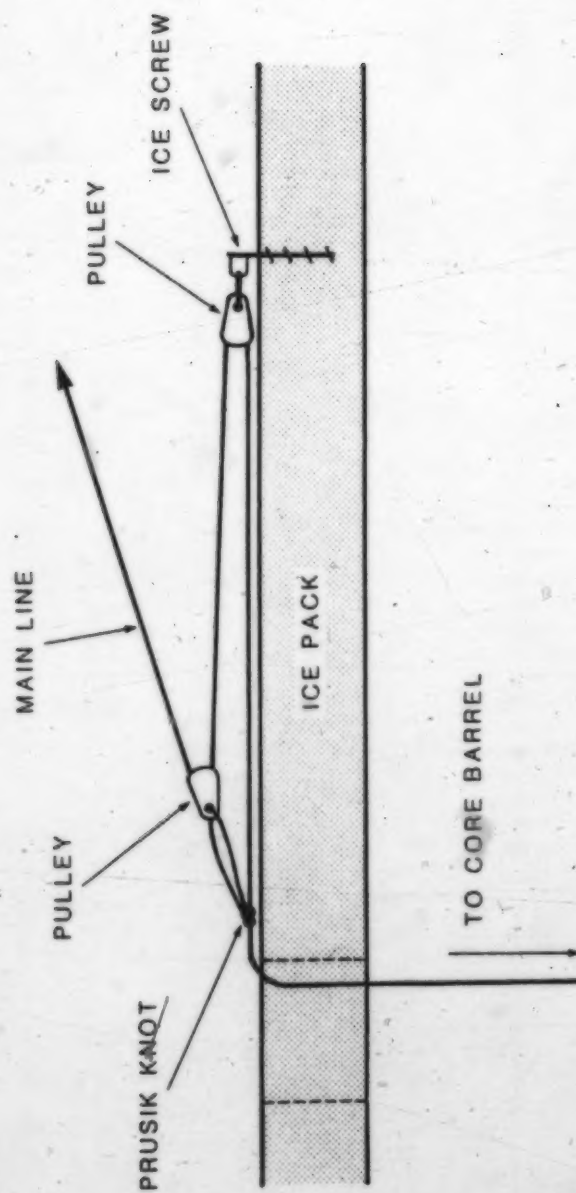


Figure 2-2. Side view of the core removal system. The mechanical advantage required for core removal is obtained from a simple pulley system set up on the surface of the ice pack. A tabular ice screw is used to anchor the pulley system to the ice pack.

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CHAPTER 3

IDENTIFICATION AND SIGNIFICANCE OF TEPHRAS ENCOUNTERED IN A CORE FROM MARY LAKE, YOHO NATIONAL PARK, BRITISH COLUMBIA. †

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INTRODUCTION

Lacustrine sedimentary environments provide an ideal setting for the deposition and preservation of volcanic ash deposits (tephras), which are valuable interpretative tools for the Quaternary geologist. This report documents the identification and significance of tephras encountered in a core recovered from Mary Lake, Yoho National Park, British Columbia. The Mary Lake site was chosen for this study because of its unique location in a high subalpine cirque immediately adjacent to the Continental Divide. The identification of tephras encountered in this study enables interpretations to be made concerning the timing of glacial events in the vicinity of Mary Lake and further confirms the tephrostratigraphy of the southern Canadian Rocky Mountain region.

Numerous studies have focused on the Holocene tephras of southwestern Alberta and southern British Columbia (e.g., Nasmith *et al.* 1967; Westgate and Dreimanis, 1967; Westgate 1977; Mathewes and Westgate 1980). Distributions of the various tephras have been mapped, and accurate dates for these deposits have largely been provided by ^{14}C dating methods (Powers and Wilcox 1964; Fryxell 1965; Westgate *et al.* 1969; Mathewes and Westgate 1980; Bacon 1983). Documentation of field characteristics, such as colour, texture, and thickness as well as distinctive phenocryst assemblages and glass shard habits, has furnished a qualitative basis for identifying many Holocene tephras.

Electron microprobe studies have demonstrated that several of the more widespread tephra units in western North America can be accurately identified on

the basis of chemical composition of either glass shards or specific phenocrysts (e.g., Smith and Westgate 1969; Westgate *et al.* 1970; Brewster and Barnett 1979; Westgate and Gorton 1981; King *et al.* 1982). The microprobe technique, being grain discrete, is less susceptible to the contamination common to those methods that use bulk separates (Westgate and Gorton 1981). The composition of the glass shard represents that of the residual magmatic liquid at the time of eruption (Smith and Westgate 1969). Unlike phenocrysts, which many contain growth zoning, glass shards are less likely to be heterogeneous, and hence they characterize the composition of an evolving magma at the point of eruption. Microprobe analysis of glass shard composition, in conjunction with other qualitative means of identification, thus aids in the establishment of a confident local tephrostratigraphy.

Since the original work of Smith and Westgate (1969), there have been many developments in the field of electron microprobe analysis (EMPA), not least of which have been the introduction and routine usage of energy dispersive systems. However, the application of these developments along with the use of electron imagery in the analysis of glass shards has not been well documented. The authors feel that the limited amount of published information concerning EMPA methodology pertaining to this application and the considerable difference between the technique employed by Smith and Westgate (1969) and that of this study warranted a detailed documentation of the analytical method.

SETTING

Mary Lake is a small, shallow, subalpine lake located 140 m southwest of Lake O'Hara (latitude 51°21'N, longitude 116°20'W) in the upper Cataract Brook drainage, Yoho National Park, British Columbia (Figure 1). Mary Lake is situated at an elevation of 2040 m, within 3 km of a high section of the Continental Divide. At present, Mary Lake is largely fed by small, ephemeral stream systems, which are not of glacial origin. Relatively small alpine glaciers occupy the headwalls of high cirques to the south (Opabin basin) and east (Oesa basin).

Fox (1974, 1979) identified four major glacial events in the Cataract Brook drainage - the "Recent", "Late Intermediate", "Early Intermediate", and "Oldest" ice advances. Mary Lake and Lake O'Hara are situated between moraine systems attributed to the Recent ice advance and the Late Intermediate ice advance. Numerous photographs taken in the Banff-Jasper area shortly after the turn of the century clearly show the Recent ice advance (or Neoglacial) very near its maximum position. Fox (1974, 1979) suggested that the Recent and Late Intermediate ice advances are post-Mazama in age and that features associated with the Oldest ice advance are correlative with the moraine systems of the Eisenhower Junction advance, the minimum age of which Rutter (1972) reported as 9330 ± 170 years BP (GSC-332).

Luckman and Osborn (1979) identified two distinct moraine systems that are present in many active cirques in the Banff-Jasper region. The younger of the two moraine systems (Cavell deposits) is correlative with the Recent ice advance

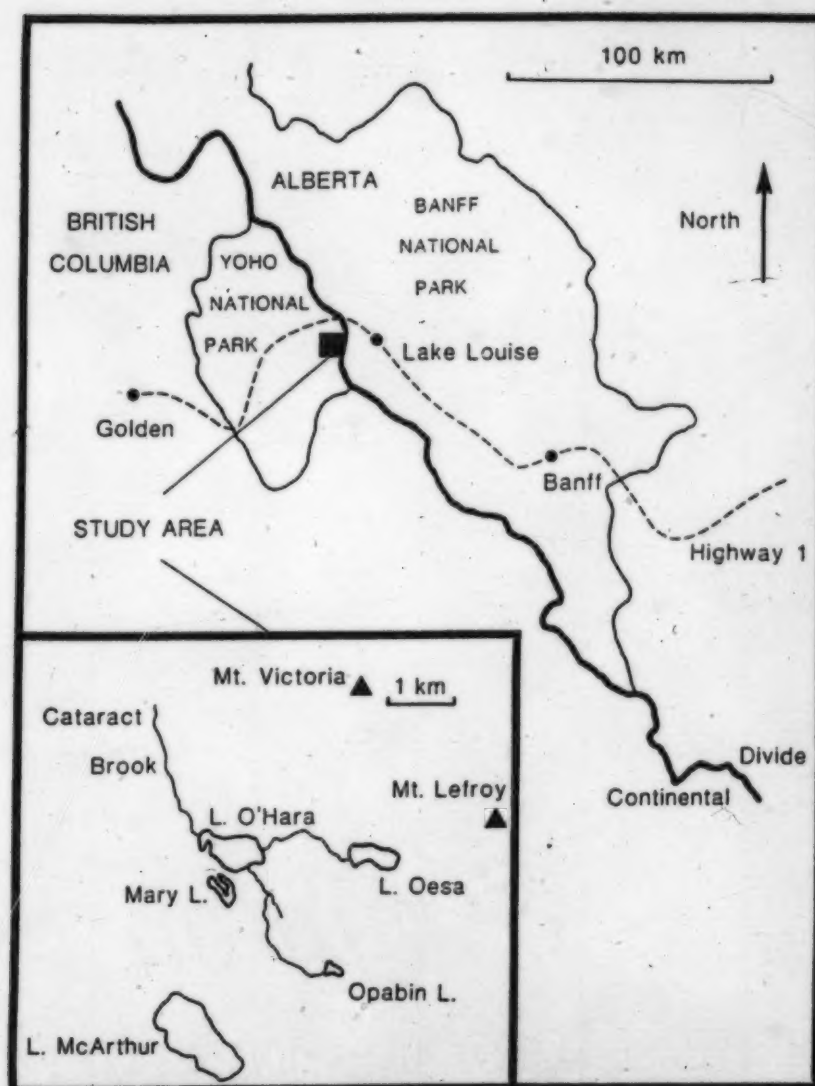


Figure 3-1. Regional map showing study area in Yoho National Park, British Columbia.

deposits of Fox (1974), which are situated approximately 2 km upvalley from Mary Lake (Figure 1). Luckman and Osborn (1979) also demonstrated that the age of the older moraine system (Crowfoot deposits) is at least 6800 years BP, based on Mazama tephra preserved in soils overlying the older moraines. The younger Cavell deposits extend 1 - 2 km beyond present ice margins and, in many circumstances, completely overlie the pre-6800 year old Crowfoot moraines (Luckman and Osborn 1979). Crowfoot moraines have not been identified in the upper Cataract Brook drainage.

The upper Cataract Brook drainage is situated within the known distribution of both Bridge River and Mazama tephra (Mathewes and Westgate 1980; Westgate and Naeser 1985). The Bridge River tephra has been dated at approximately 2350 years BP (Mathewes and Westgate 1980), and the age of Mazama tephra has been reported as approximately 6800 years BP (Bacon 1983).

METHODS

Core sampling and Initial tephra identification

A 6 cm diameter core (1.25 m in length) was recovered from a shallow area of Mary Lake situated distal to inflowing streams. The core was recovered in January of 1983 by driving a 3 m length of plastic (ABS) pipe into surficial bottom sediments with a sledge hammer. A modified cupboard hinge installed inside the bottom of the core barrel worked effectively as a core catcher. Core sample

disturbance was kept to a minimum by allowing the core to freeze inside the core barrel before it was transported (by cross-country ski) and by cutting off the core barrel before the sample was thawed and split. Sampling during winter conditions through a hole bored in the lake ice was found to be advantageous because the ice surface provided a stable platform from which leverage could be applied for core removal.

Tephra encountered in the core were tentatively identified on the basis of features observed in freshly split core and by distinctive properties discernible from standard petrographic techniques and scanning electron microscopy. These properties included colour, texture, glass shard habit, and phenocryst assemblages. Phenocryst assemblages were determined by only considering phenocrysts that were attached to or encased in glass.

Electron microprobe analysis of glass shards

Sample Preparation

Subsamples of each tephra were disaggregated and sieved to the 70 mesh (0.20 mm) fraction. The magnetic fraction was removed by hand magnet. Relatively pure fractions of fresh glass were separated using a tetrabromethane heavy-liquid separation. A final sieving to yield a 200 mesh (0.075 mm) fraction was performed to remove remaining coarse-grained shards, which tend to be vesicular. Approximately 0.2 g of each of the two purified separates was mounted as standard polished thin sections.

Microprobe analysis

The analytical technique employed is a modification of the technique developed at the University of Alberta by D.G.W. Smith. A rastered beam was used in contrast to continuously moving a point beam during the analysis (Smith *et al.* in preparation). Wavelength dispersive analysis (WDA) and energy dispersive analysis (EDA) were performed simultaneously on an ARLSEMQ electron microprobe fitted with an ORTEC EEDS energy dispersive system (EDS). The samples were viewed simultaneously with secondary electron (SE) and back-scattered electron (BSE) imagery to avoid glass shards with visible bubbles, phenocrysts, microlites, and inclusions. In addition, the raster area of the beam (analytical field) was adjusted to lie well within the shard margins. This use of a rastered beam, with resultant near-instantaneous beam dwell time, is desirable when analyzing volcanic glasses, which are unstable under prolonged electron bombardment. The raster area was minimized to $20 \mu\text{m}^2$ to avoid significant defocussing effects in the crystal spectrometers. This area was large enough to prevent scorching visible on the BSE imagery.

The elements Na, K, Ca, and Fe provide the maximum discrimination between Holocene - Late Pleistocene age tephtras of western Canada (Smith and Westgate 1969; Westgate 1977) and were, therefore, determined by the more accurate and generally accepted WDA, in preference to EDA.

Each selected grain was analyzed for a live count time of 10 seconds, simultaneously for both WDA and EDA. Using the ORTEC EEDS system, the

total spectrum counts per second (CPS) and the total counts in the silicon region of interest (SIROI) were examined for each 10 second spectrum to identify the presence of bubbles (reduced CPS) and phenocrysts and (or) microlites (change in the CPS and counts in the SIROI). In addition, visual examination of the spectra was performed to identify large discrepancies in the spectra. Accepted spectra were accumulated to a total of 240 seconds live count time.

This 240 second spectrum and the corresponding 240 second WDA data represented the combined spectra of 24 individual glass shards and were processed as a single analysis. Four separate analyses of this nature were obtained from each sample, and a fifth analysis was generated for each sample by combining the initial two 240 second spectra. The latter analysis was generated to provide an enhanced statistical base for the background corrections.

The obsidian working standard EPS/11-6 = CCNM211 (Smith and Westgate 1969) was included in the analytical run in order to calculate the element concentrations in the sample. The concentrations of Mg were calculated from those of a kaersutite standard, whereas the concentrations of Ti were calculated from default standards (Smith and Gold 1979). Routine data reduction, including full matrix (ZAF) corrections, was performed on the combined WDA - EDA data using the FORTRAN FOUR EDATA2 program (Smith and Gold 1979).

RESULTS

Core Description

The Mary Lake core comprises two distinct sediment types: organic-rich mud (gyttja) and underlying inorganic clastic sediments (Figure 2). The lower 41 cm of the core is composed of massive, light grey, fine to medium sands with thin (0.8-1.6 cm thick) silty interbeds in the upper 15 cm. A pebbly horizon, present 21 cm above the core base, contains very angular clasts as large as 3.5 cm x 5.0 cm. Immediately overlying the massive sands is 32 cm of poorly sorted, matrix-supported, dark grey, pebbly muds containing clasts as large as 3.2 cm x 4.8 cm. The large clasts show normal grading within this interval. The uppermost 52 cm of the core is brown, massive gyttja, which contains two tephra tentatively identified prior to microprobe analysis as Bridge River tephra (1.5 cm thick) and Mazama tephra (7.1 cm thick). The Mazama tephra separates the overlying gyttja from underlying, inorganic, clastic sediments.

Mazama tephra displayed a slightly reddish colouration (5YR 7/2) in freshly split core, whereas Bridge River tephra appeared light grey (2.5YR 7/0). A simple "feel" test for texture demonstrated that Mazama tephra is finer grained than Bridge River tephra. These characteristics concur with the field observations of previous workers concerning the two tephra (Duford 1976; Luckman and Osborn 1979). Petrographic analyses and scanning electron microscopy revealed that the phenocryst assemblages and glass shard habits of the two tephra are also comparable with documented characteristics of Bridge River and

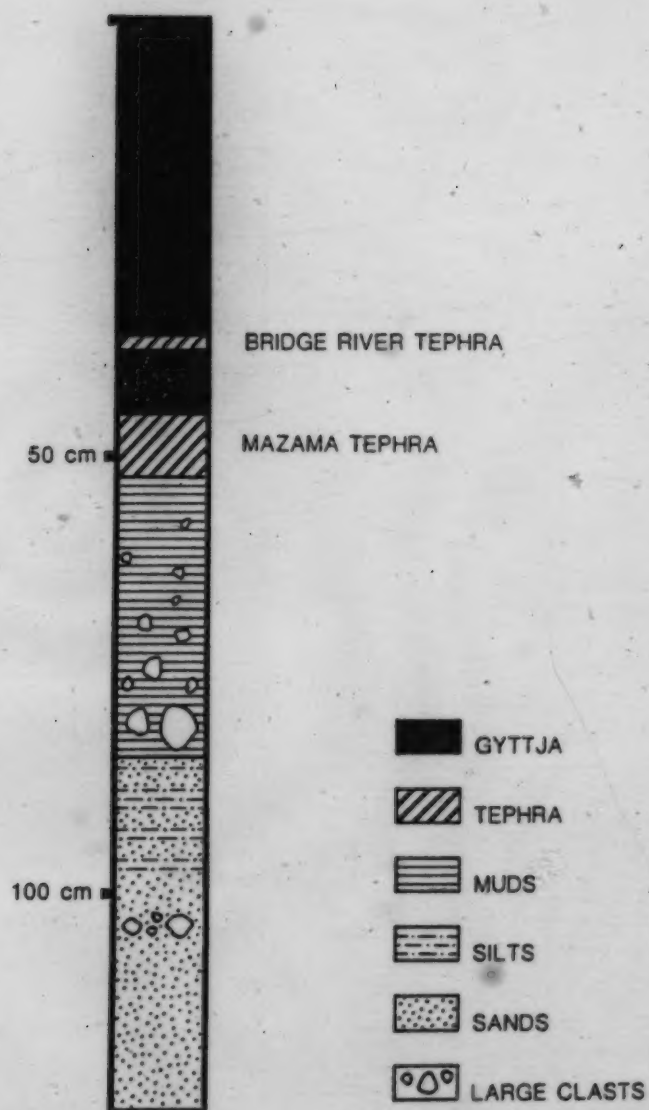


Figure 3-2. Schematic sketch of the Mary Lake core.

Mazama tephra (Nasmith *et al.* 1967; Mathewes and Westgate 1980) (Table 1). Inclusion-rich plagioclase phenocrysts are abundant in Bridge River tephra (Plate 1). Biotite phenocrysts are also common in Bridge River tephra and were not observed in Mazama tephra. Bridge River glass shards are typically "chunky" and display lineated, lensoid gas vesicles (Plate 2), whereas Mazama glass shards are commonly thin, bubble-wall fragments (Plate 3).

Results of electron microprobe analyses

For those elements whose concentration were calculated from the obsidian standard, the ZAF applied by EDATA2 was 0.986, i.e., 1.4% of the uncorrected value. The proximity of these ZAF values to unity reflects the similar matrices of samples and standard and is highly desirable in any matrix-dependent quantitative comparative analytical technique. Slightly higher ZAF corrections were generated for Mg and Ti, whose concentrations were calculated from a kaersutite standard and a default standard, respectively. However, these elements, which are present at low levels of concentration, are not routinely used to discriminate between glass compositions of the various tephra units of western North America.

The Mg values that were generated initially by EDA were found to be in error because of poor background fit on the low-energy end of the spectrum, which may have a significant effect on the relatively small MgK α peak. The Mg determinations were subsequently rerun using WDA. For these analyses, the

Table 3-1. Characteristics of tephra in the study area

	Bridge River (Mathewes and Westgate, 1980)	Bridge River (this study)	Mazama (Mathewes and Westgate, 1980)	Mazama (this study)
Plagioclase	Abundant, inclusion rich	Present with inclusions	Common	Present
Clinopyroxene	Common, green	Present, green	Sparse, pale green	Sparse
Orthopyroxene	Common	Present	Common	Present
Hornblende	Common	Present	Common	Present
Commingtonite	Absent	Absent	Absent	Absent
Biotite	Common	Present	Absent	Absent
Glass	Chunky shards with lineated lensoid vesicles	Chunky shards with lineated lensoid vesicles	Thin, bubble-wall shard fragments	Thin, bubble-wall shard fragments

Plate 3-1. (A) Photomicrograph of an inclusion-rich plagioclase phenocryst from the Bridge River tephra. Transmitted light, crossed Nicols. (B) Backscattered electron photograph of the Bridge River tephra. Large glass-encased plagioclase phenocryst (p) contains inclusion of hornblende (h). Note the well-preserved structure of the highly vesicular glass (g).

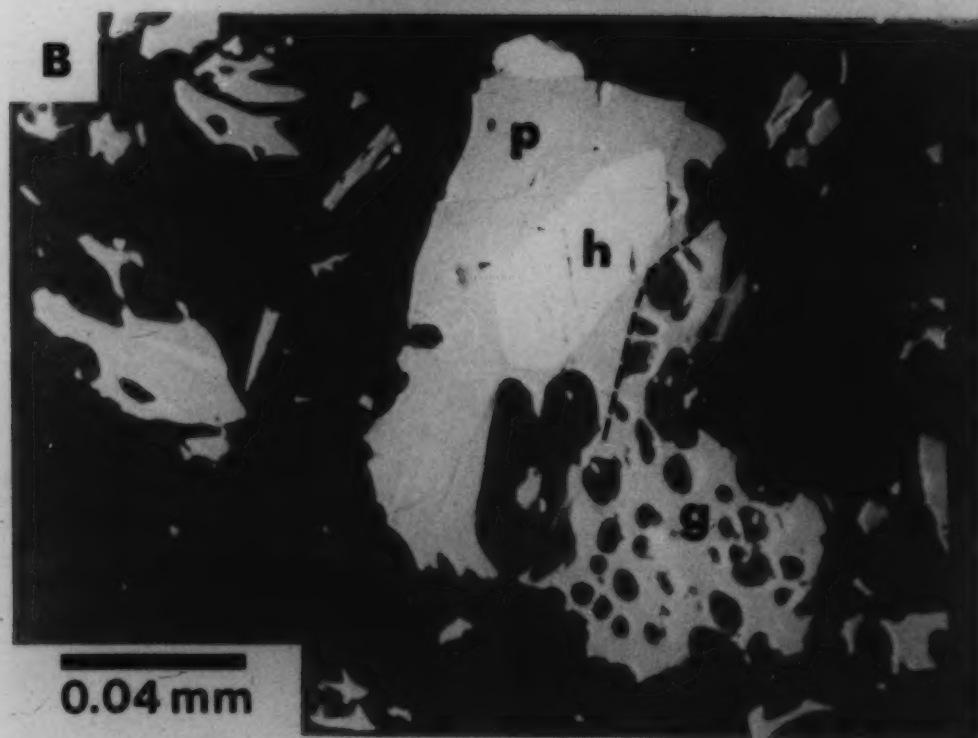
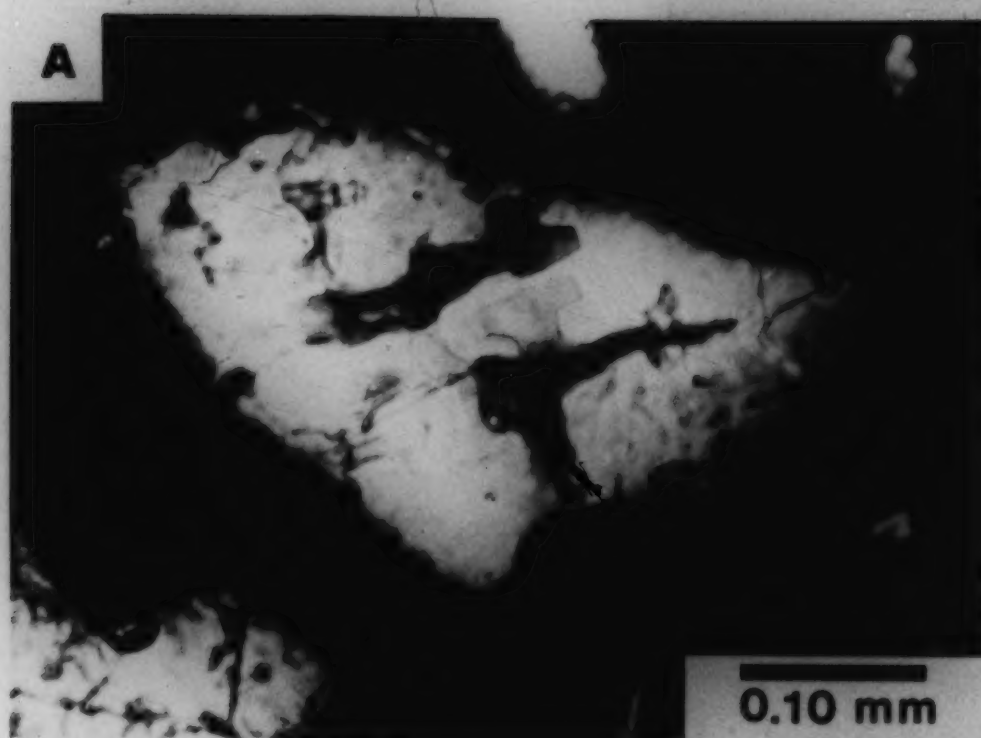
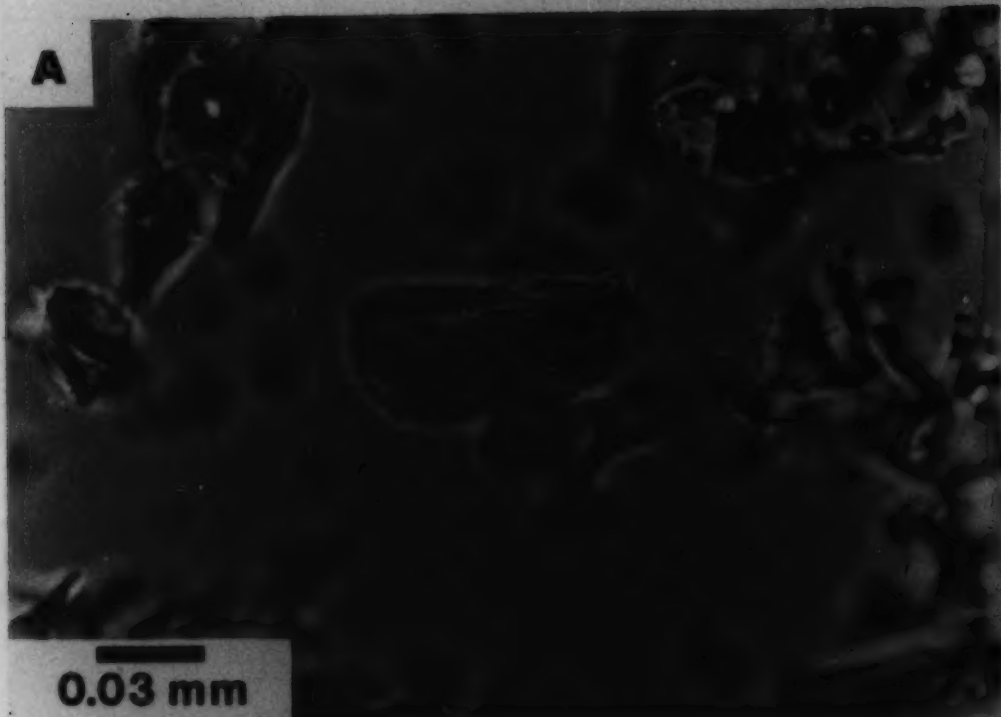


Plate 3-2. (A) Photomicrograph and (B) scanning electron micrograph of Bridge River tephra glass shards. Note the chunky glass shard habit and the lineated, lensoid gas vesicles.

A



B

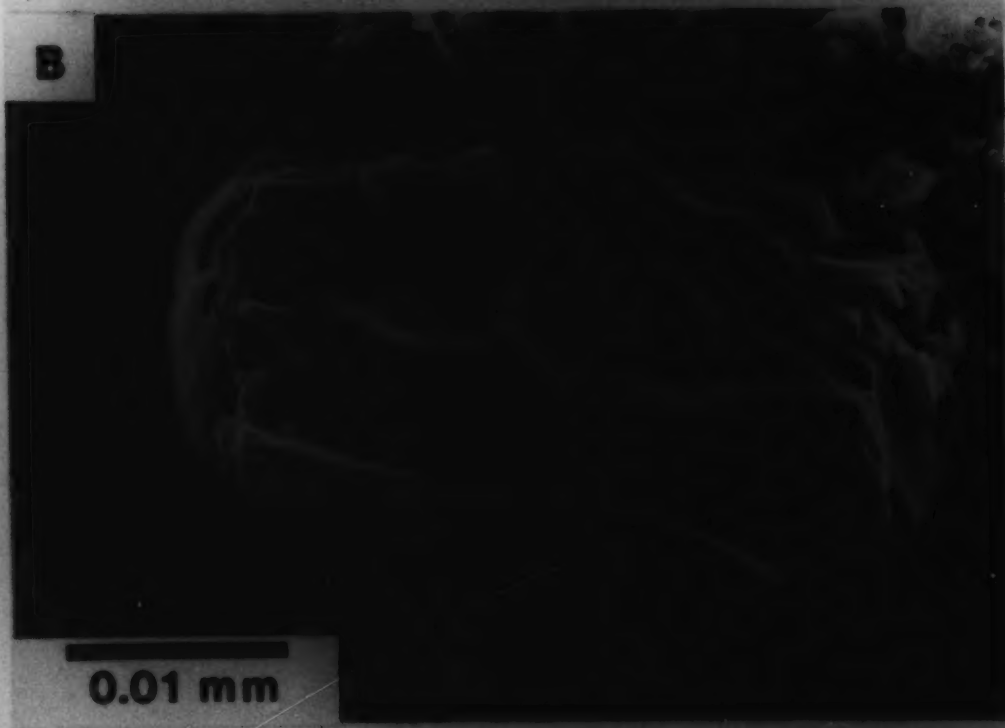


Plate 3-3. (A) Photomicrograph and (B) scanning electron micrograph of Mazama tephra glass shards that exhibit distinctive thin, bubble-wall fragment glass shard morphology.

A

0.03 mm

B

0.02 mm

uncertainties in MgO were calculated from theoretical error curves and were based on counting statistics.

The weight percent oxides calculated, water free, are presented with uncertainty limits in Table 2. The overall analytical precision was calculated for each oxide (except MgO) in both Mazama and Bridge River analyses. The limits of uncertainty, calculated at the 95% confidence level, include the errors generated by counting statistics in both the samples and the standard, compositional inhomogeneity, and possible inclusion of microlites and gas vesicles in the analyses. It is apparent that the results of this study are comparable to the values compiled for Mazama and Bridge River shards by Westgate and Gorton (1981). In addition, the uncertainty in the analyses is generally significantly less than that required to permit discrimination between compositionally distinct populations (Table 2).

The glass compositions were plotted on a FeO-CaO-K₂O ternary diagram (Figure 3), as employed by many workers (e.g., Westgate 1977; Westgate and Evans 1978; Westgate and Gorton 1981; Osborn 1985) to distinguish between the more widespread tephra units of the Holocene - Late Pleistocene age in western North America. All five analyses of the tephra tentatively identified as Mazama plot in a tight cluster within the Mazama compositional field, thereby confirming the initial identification based on field relations, shard habit, and mineral assemblage.

All five analyses of the tephra tentatively identified as Bridge River plot in

Table 3-2. Electron Microprobe results

Wt.% oxide	Technique	Mazama (this study)	Mazama (Westgate and Gorton, 1981)	Bridge River (this study)	Bridge River (Westgate and Gorton, 1981)
SiO ₂	EDA	72.94±0.70	72.58±0.31	74.58±0.45	74.35±0.73
TiO ₂	EDA	0.45±0.14	0.48±0.03	0.35±0.08	0.36±0.04
Al ₂ O ₃	EDA	14.50±0.14	14.40±0.16	13.98±0.18	13.72±0.27
MgO	WDA	0.37±0.02	0.56±0.08	0.35±0.02	0.44±0.09
CaO	WDA	1.70±0.04	1.66±0.10	1.63±0.08	1.40±0.18
FeO	WDA	2.07±0.06	2.11±0.08	1.64±0.07	1.62±0.18
Na ₂ O	WDA	4.98±0.20	5.18±0.20	4.24±0.32	4.61±0.15
K ₂ O	WDA	2.79±0.03	2.70±0.11	3.12±0.04	3.16±0.14
Cl	EDA	0.20±0.04	0.18±0.01	0.11±0.03	0.12±0.03

Notes: Microprobe operated at 15 kV; probe current, 4.1 nA; Emission current, 200A; take-off angle, 52.5°; live count time, 240 s. Data reduction by EDATA2. Total Fe given as FeO. Analyses presented water free. Uncertainties calculated at the 95% confidence level.

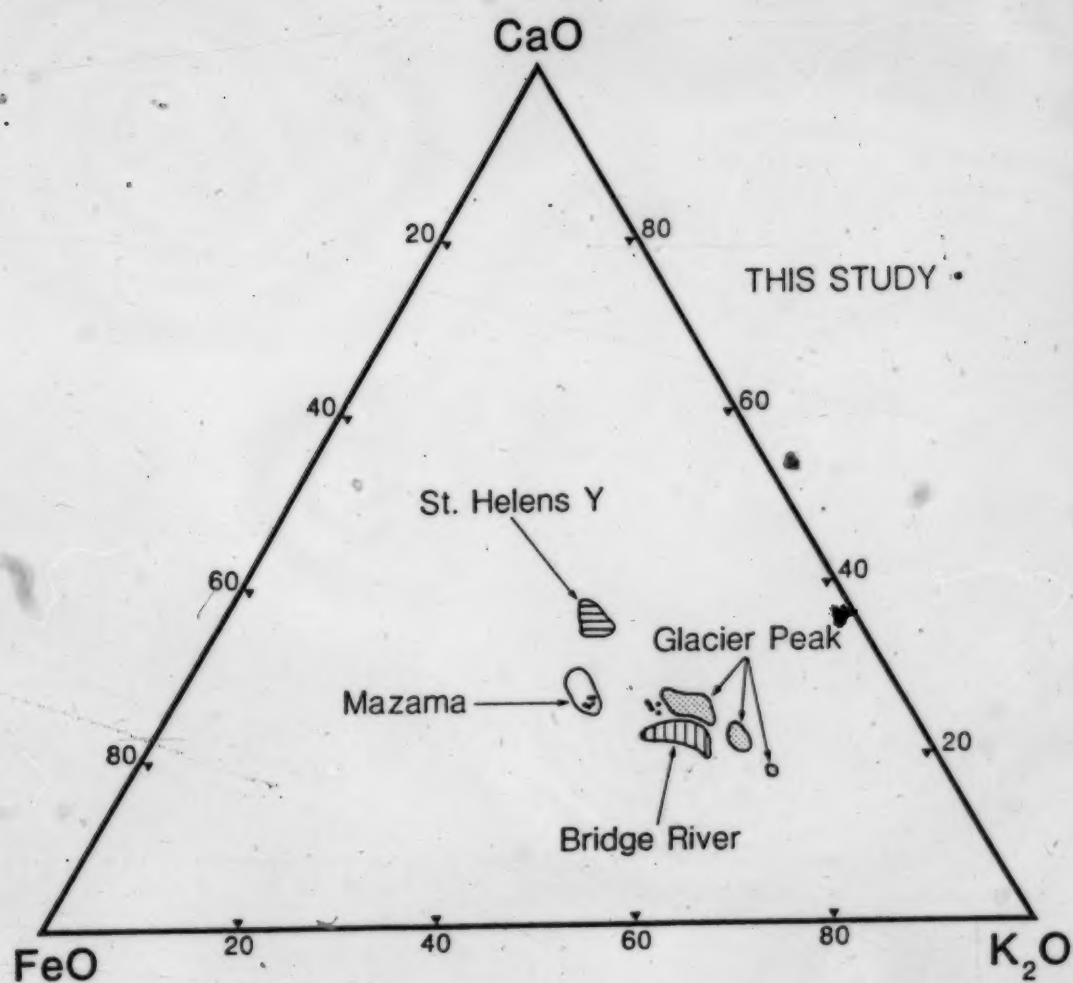


Figure 3-3. FeO-CaO-K₂O ternary diagram showing the compositional fields of the more widespread Holocene - Late Pleistocene age tephros of western North America (Westgate and Evans 1978). The 10 analyses of this study are also plotted.

a cluster immediately outside the composition field of Bridge River, adjacent to the Glacier Peak (Chiwawa Bed) composition field. This may be explained by postulating that the tephra unit corresponds to (1) an unknown unit; (2) reworked Glacier Peak tephra; (3) weathered or altered Bridge River tephra; (4) Bridge River tephra where previously defined compositional field is incomplete; or (5) Bridge River tephra where the present analyses are affected by inclusion of plagioclase microlites, resulting in anomalous concentrations of CaO.

The field relations, mineral assemblage (especially the inclusion-rich plagioclase), shard habit, and excellent preservation of glass shards refute points 1, 2 and 3. In addition, the generally excellent preservation of the delicate morphology of the glass shards (Plates 2 and 3), the sharp contacts of the tephra unit with the enclosing sediments, and a complete phenocryst assemblage strongly suggest the absence of significant reworking. Finally, the Mary Lake locality lies within the known distribution of Bridge River tephra and outside the hitherto defined east-southeast-trending plume of the Glacier Park (Chiwawa Bed) unit (Westgate and Evans 1978) as well as the north-northeast-trending plume of the St. Helens Y unit (Westgate *et al.* 1969).

The distinct possibility remains that the results represent an expansion of the previously defined compositional field for Bridge River tephra (point 4). However, the authors contend that point 5 most readily explains the observed deviation and is reflected in the elevated values for CaO relative to the compiled data of Westgate and Gorton (1981). Qualitative analysis of the plagioclase

phenocrysts indicates a composition of calcic-andesine that is considerably more calcic than the encasing glass. The possible inclusion of plagioclase microlites in the analytical field results from the disparity between the excitation volume of primary X-rays and the surficial nature of both BSE and SE imagery. Microlites of the order of $1.0\text{ }\mu\text{m}$ in size and greater that occur on the surface are readily detected. However, those occurring below approximately $1.0\text{ }\mu\text{m}$ of the surface and within the excitation volume (approximately $3.0\text{ }\mu\text{m}$ depth) may not be detected by BSE or SE imagery. Provided the microlites did not occupy a significant portion of the excitation volume of any of the 10 second analyses, their contributions would be inseparable from the relatively large statistical uncertainty in the CPS and SIROI, and the spectrum would have been accepted, resulting in slightly elevated CaO values. This window of vulnerability represents the main pitfall of the rastered beam technique.

DISCUSSION

Backscattered and secondary electron imagery provides discrimination superior to that of the generally poor light optical systems with which most microprobes are fitted. The procedure used in this study was developed to take advantage of the excellent imaging system fitted to the SEMQ. Many microprobes are equipped with reflected light optics only, which provides substantially less discrimination between silicate phases than the accompanying electron imagery and precludes the effective use of the transmitted-light

dependent point beam method. Therefore, the authors consider the rastered beam technique to be the logical alternative for use on such microprobes.

The rastered beam technique has the following advantages over the point beam method: (1) increased speed of analysis; (2) improved spatial resolution; (3) precise selection of the analytical field, with no opportunity for "running off the grain", caused by operator error or mechanical "slop" in the stage; and (4) increased phase contrast and, hence, discrimination of surface and near-surface ($< 1 \mu\text{m}$ depth) artifacts. However, the rastered beam technique apparently suffers from the inability to visually discriminate subsurface (> 1 and $3 \mu\text{m}$ depth) artifacts that occupy a small portion of the excitation volume of the analytical field. It is an inherent property of the rastered beam to smooth these minor contaminant-derived contributions such that they are also undetected on examination of the spectrum.

The identification of Bridge River and Mazama tephras in Mary Lake lacustrine sediments permits the calculation of mean annual sedimentation rates for the post-Bridge River and the Mazama - Bridge River time periods. Assuming that sediments have not been removed by current activity or by subaerial exposure, mean post-Bridge River (2350 years BP) sedimentation rates are approximately 0.15 mm/year. Mazama - Bridge River (2350 - 6800 years BP) mean sedimentation rates are considerably lower, of the order of 0.02 mm/year. The sedimentation rates presented here are considered approximate at best, as they are derived from sediment thickness values that may be significantly

reduced by post-depositional consolidation. The absence of palaeosols, erosional surfaces, and sedimentary structures associated with current activity indicates the post-Mazama (6800 years BP) sediments in the Mary Lake core have not been subjected to major erosional events or periods of subaerial exposure resulting from lower lake water levels. However, it is possible that slow, continual transportation of fine-grained sediments from the shallow areas to the basin centre, by resuspension and redeposition, has influenced sediment accumulation at the coring location.

Leonard (1981, 1986) suggested that Holocene glaciolacustrine sedimentary environments in northern Banff National Park (Hector, Bow, Crowfoot and Boundary lakes) were significantly influenced by regional glaciological conditions. Relatively high sedimentation rates occur during, and up to approximately a century following, periods of increased upvalley ice extent, whereas low sedimentation rates correspond to periods of reduced ice extent (Leonard 1981). Periods of relatively rapid sedimentation prior to 7000 years BP and after 3500 - 2800 years BP are attributed to increased upvalley ice extent during the earlier and latter portions of the Holocene (Leonard 1981). The relatively slow sedimentation rates representing the Mazama - Bridge River period of the Mary Lake core are consistent with the long-term sedimentation rate variations presented by Leonard (1981) for the same period and are also presumed to be related to climatic conditions associated with less extensive upvalley ice.

The presence of Mazama tephra in undeformed lacustrine sediments in the Mary Lake core implies that glaciers had ~~receded~~ receded from the vicinity of Mary Lake prior to 6800 years BP. Consequently, moraine systems downvalley from Mary Lake, attributed to the Late Intermediate advance (Fox 1974, 1979), are older than 6800 years BP and are early Holocene or Late Wisconsinan in age. These findings concur with the conclusions of Luckman and Osborn (1979), who demonstrated that glaciers in the central Rocky Mountains had receded very near or beyond their Cavell (Neoglacial) maxima prior to the Mazama ash fall.

Palaeoclimatic reconstructions from the Tonquin Pass area in Jasper National Park indicate that warmer climatic conditions prevailed during the period 8040 - 4300 years BP, in contrast to the cool, moist conditions that have persisted during the last 1700 years (Kearney and Luckman 1983). The above 4300 year BP date was based on the presence of a St. Helens Y tephra set in the Tonquin Pass section. The age of this St. Helens tephra in the Tonquin Pass section has recently been revised to ca. 3400 years BP by bracketing ^{14}C dates (Luckman *et al.* 1986). A similar climatic record is presumed for the upper Cataract Brook valley, as both study areas are proximal to the Continental Divide and are at similar elevations (approximately 2000 m above sea level). Considering the limited extent of the Cavell advance in the study area and that the Cavell moraine systems represent the most significant glacial activity subsequent to the pre-6800 years BP Crowfoot advance, it is likely that the upper Cataract Brook drainage was ice free during the warmer portions of the middle Holocene.

CONCLUSIONS

(1) The positive identification of Mazama tephra stratigraphically overlain by a thinner Bridge River tephra unit in the Mary Lake core confirms the local tephrostratigraphy initially established by the authors on the basis of qualitative observations.

(2) The Late Intermediate moraine systems that Fox (1974, 1979) regarded as post-Mazama in age are older than 6800 years BP and are early Holocene or Late Wisconsinan in age.

(3) The most significant glacial event of the post-Mazama time period in the Cataract Brook drainage occurred during the Neoglacial (Cavell advance), and consequently, the upper Cataract Brook drainage may have been ice free during warmer portions of the Holocene.

(4) Mean annual sedimentation rates determined from tephra depths in the Mary Lake core were found to be higher during post-Bridge River time (2350 years BP) than during the Mazama- Bridge River period (6800 - 2350 years BP). Presumably, the difference in sedimentation rates for the two time periods is a result of warmer and drier climatic conditions during the mid-Holocene.

(5) Analyses of glass shard composition by grain discrete EMPA are potentially subject to contamination from glass-encased microlites. Therefore, microprobe analyses of shards, generated without the aid of high-resolution transmitted-light optics and (or) BSE or SE imagery, may yield anomalous compositions. This is particularly true for analyses of tephras that have abundant

gas vesicles and microlites.

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CHAPTER 4

LATE QUATERNARY HISTORY OF THE LAKE O'HARA REGION, BRITISH COLUMBIA; AN EVALUATION OF SEDIMENTATION RATES AND BULK AMINO ACID RATIOS IN LACUSTRINE RECORDS. †

† A version of Chapter 4 has been accepted for publication. Reasoner M. A.,
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INTRODUCTION

The timing of Late Wisconsinan deglaciation and variations of Holocene palaeoenvironments of the Canadian Rocky Mountains have been of interest to researchers for many years. The objectives of this report are: (1) to provide limiting dates for deglaciation of alpine and subalpine cirques that are situated in close proximity to the Continental Divide; (2) to evaluate the reliability of total sedimentation rate data derived from lacustrine cores as a proxy record of upvalley ice activity; and (3) to test the chronological accuracy of amino acid D/L ratios determined from bulk gyttja (organic mud) of known age. To this end, a suite of 22 cores were recovered from alpine Opabin Lake and subalpine Lake O'Hara in the central Canadian Rocky Mountains (Figure 1).

A number of studies have provided limiting radiocarbon dates for deglaciation of main valleys in the central Canadian Rockies (e.g., Westgate and Dreimanis 1967; Harrison 1976; Fergusson and Osborn 1981; MacDonald 1982; Levson and Rutter 1986). Relatively few studies, however, have established limiting radiocarbon dates from alpine areas (Luckman and Kearney 1986; Beaudoin 1986) or areas adjacent to the Continental Divide (Hench *et al.* 1979; Luckman and Osborn 1979). Radiocarbon dates obtained from cirques situated near the Continental Divide are regionally significant in that they provide a limiting case for the deglaciation of downvalley locations.

Leonard (1986a, 1986b, 1987) has provided proxy records of Holocene glacial activity in the form of lacustrine sedimentary records from lakes near the

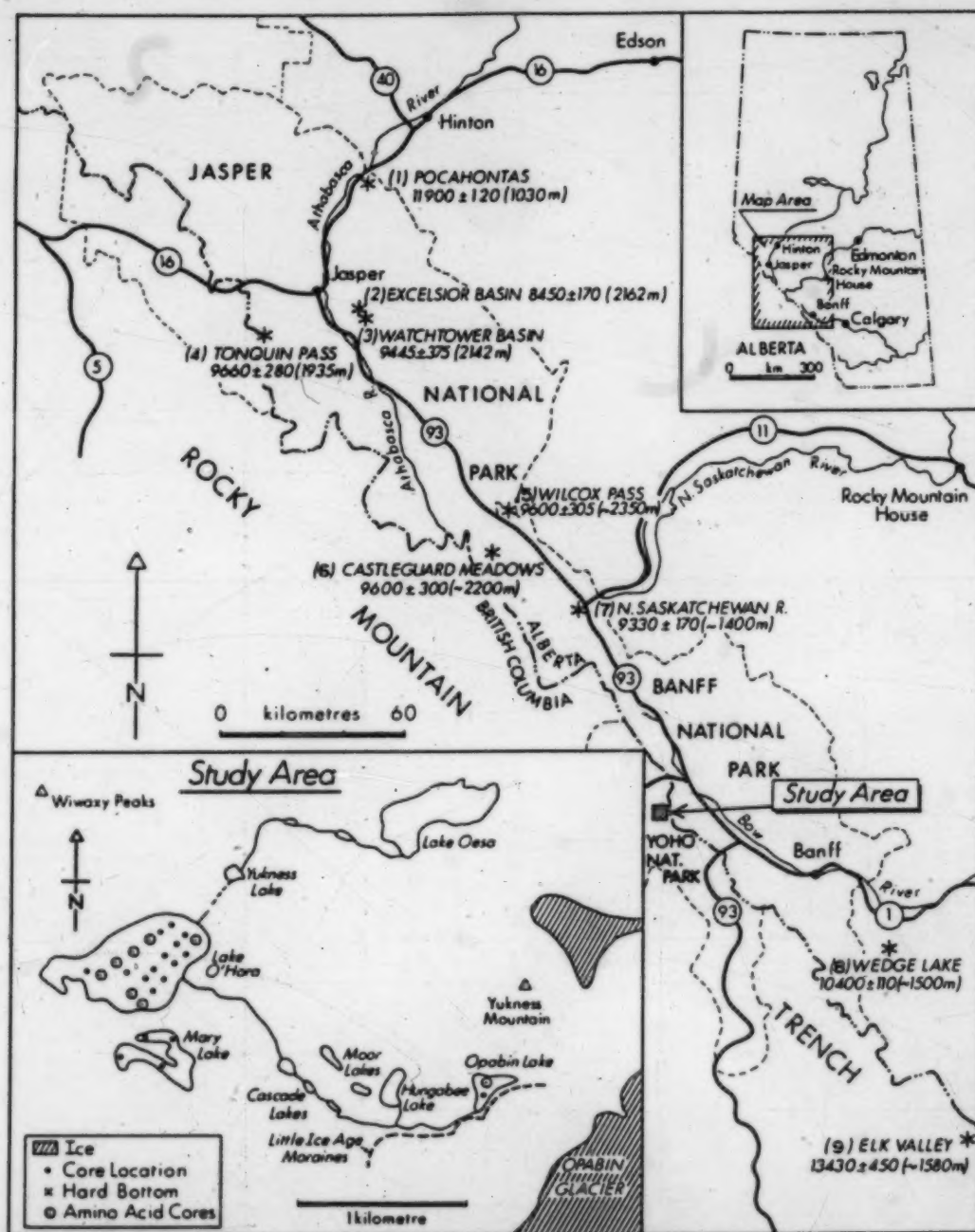


Figure 4-1. Regional map of the central Canadian Rocky Mountains showing the location of the study area. Also included on the regional map are the locations of limiting deglaciation dates, and their respective elevations, provided by: (1) Levson and Rutter 1986; (2) Luckman and Osborn 1979; (3,4) Luckman and Kearney 1986; (5) Beaudoin 1986; (6) Henoch *et al.* 1979; (7) Westgate and Dreimanis 1967; (8) MacDonald 1982; (9) Ferguson and Osborn 1981.

headwaters of the Bow River. These studies indicate a relationship exists between glacial sediment input and upvalley glacial activity (in lakes that are fed directly from a glacial source). This relationship provides the basis for interpreting total sedimentation rate data from the Opabin Lake cores. The recovery of multiple cores containing well dated chronostratigraphic markers from Lake O'Hara allows the evaluation of this relationship in a case where inflowing glacial streams are interrupted by upstream lakes.

Many varieties of fossils are now routinely analyzed in order to determine the D/L ratios of amino acids for relative and absolute dating of sediments. Most investigations have centered on a variety of marine, freshwater, and terrestrial molluscs, as well as mammal bones, wood, and soils (Rutter *et al.* 1985). Gytja is a pulpy, freshwater organic mud, that contains organic material from a variety of sources. If a consistent relationship between amino acid ratios and the known ages of the gytja subsamples can be demonstrated, then the method might be of considerable use as a supplement and check on conventional dating methods of lacustrine cores.

The Lake O'Hara cores provide an ideal opportunity to evaluate amino acid D/L ratios derived from bulk gytja samples because: (1) The recovered cores show a consistent stratigraphy, each containing two tephras and a sharp basal contact separating gytja from underlying clastic sediments; (2) The presence of accurately identified tephras combined with basal ^{14}C dates provides excellent time control of the deposition of the sediments and; (3) The

relatively constant thermal history of the glacial lake setting reduces temperature variations that influence racemization rates of amino acids in sediments.

PREVIOUS WORK

Radiocarbon dates obtained from main outlet valleys in the Canadian Rockies (Figure 1) indicate that valley glaciers were in retreat by ca. 11,000 - 13,000 years BP (Harrison 1976; Jackson 1980; Fergusson and Osborn 1981; MacDonald 1982; Levson and Rutter 1986). Limiting ^{14}C dates from alpine areas of ca. 9600 years BP are provided by Henoch *et al.* (1979), Luckman and Kearney (1986) and Beaudoin (1984). Luckman and Osborn (1979) report a limiting date for deglaciation of the Continental Divide at Tonquin Pass (Figure 1) of 9660 ± 280 years BP (GSC - 456). Finally, Carrara *et al.* (1986) used tephrochronology to demonstrate that Marias Pass (south of Glacier National Park, Montana) was ice-free by 11,400 years BP.

Following the Late Wisconsin deglaciation, moraine and rock glacier deposits provide evidence for a limited glacial advance in the area of the Continental Divide, named the Crowfoot Advance by Luckman and Osborn (1979). These moraines are overlain by Mazama tephra indicating that they were formed prior to 6,800 years BP. In general, moraines of the Crowfoot Advance are less extensive than moraines of the younger, Late Neoglacial ice advance; also called the Cavell Advance (Luckman and Osborn 1979). Several recent studies of the Holocene glacial history of western Canada have indicated that, in

general, the Late Neoglacial ice advance reached its maximum extent during the mid to late nineteenth century (e.g., Luckman 1986; Ryder and Thomson 1986; Osborn 1986).

Leonard (1986a, 1986b, 1987) employed lacustrine sedimentary records in reconstructing the Holocene glacial history of the upper Bow Valley and demonstrated that variations in glacial sediment input are related to upvalley glacial activity. Periods of increased ice extent are also periods of rapid sedimentation, while decreased ice extent is reflected in slower sedimentation (Leonard 1986a, 1986b). An approximate basal date of ca. 9000 years BP for the Crowfoot Lake record is based on downcore extrapolation from the Mazama tephra (Leonard 1987). Smith (1981) documented the effect of the opening of an upstream proglacial lake on the lacustrine sedimentary record of Bow Lake.

Bulk amino acid studies

Relatively little reported research is available concerning the amino acid racemization in bulk sediment. Soils (Forman *et al.* 1982; Harden *et al.* 1985; Colman *et al.* 1986) and marine and freshwater sediments, however, have been investigated. Limmer and Wilson (1980) published results on the amino acid content of a sequence of paleosols from New Zealand and suggested that the differential disappearance of particular amino acids from paleosols of varying age could be useful for dating buried soils beyond the range of radiocarbon dating. Mahaney *et al.* (1986) found that D/L ratios of aspartic acid derived from

^{14}C dated paleosols from Mt. Kenya, East Africa increased with increasing age of the soil. Marine sediments spanning the last 9000 years from Saanich Inlet, British Columbia were analyzed by Kvenolden *et al.* (1970) who found that the percentages of D enantiomers increased with age. Bada *et al.* (1970) analyzed a deep - sea sediment core from the floor of the Atlantic Ocean and found that isoleucine is increasingly racemized with depth. Late Wisconsinan lacustrine sediments from Lake Ontario have been investigated by Schroeder and Bada (1978) who showed that D/L ratios of aspartic acid increased with depth and therefore, with age. Other similar studies include the analyses of fresh water sediments from Lake Biwa, Japan (Tanaka and Handa 1979) and from Clear Lake, California (Blunt *et al.* 1981).

SETTING

Lake O'Hara and Opabin Lake are located in the Upper Cataract Brook Valley (latitude $51^{\circ} 21' \text{N}$, longitude $116^{\circ} 20' \text{W}$) in Yoho National Park, British Columbia (Figure 1 and Plate 1). The upper Cataract Brook drainage is a region of considerable local relief and is bounded to the east by a high section of the Continental Divide that forms the crest of the Lake Louise group of peaks. Peaks in excess of 3000 m elevation in the area typically host a number of relatively small alpine glaciers.

Fox (1974, 1979) identified four major glacial events in the upper Cataract Brook drainage - the "Recent", "Late Intermediate", "Early Intermediate" and the



Plate 4-1. Stereo triplet of the Lake O'Hara area showing the locations of Lake O'Hara (loh), Opabin Lake (opb), Opabin Glacier (og), Late Neoglacial moraines (n), and Late Intermediate moraines (li).



"Oldest" ice advances. Lake O'Hara and adjacent Mary Lake are situated approximately midway between the moraine systems attributed to the Recent (Little Ice Age) and Late Intermediate ice advances (Fox 1974, 1979). Reasoner and Healy (1986) demonstrated that the age of the Late Intermediate moraine system is at least 6800 years BP based on the identification of Mazama tephra in a core from Mary Lake (Figure 1).

Lake O'Hara is situated at approximately 100 m below timberline at an elevation of 2015 m. The surface area of the lake is approximately 0.5 km² and the maximum measured depth 42 m. The lake is primarily fed by three small streams, two of which originate from glacial sources less than 3 km distant in the Oesa and Opabin cirques (Figure 1 and Plate 1). The third inflowing stream drains directly from Mary Lake which presently occupies an ice-free subdrainage.

The approximate bathymetry of the Lake O'Hara basin was determined from soundings at the core locations in conjunction with depths obtained from acoustic profiles. The deepest area of the lake (> 40 m) is situated in the steep-sided eastern portion of the basin (Figure 2). The acoustic profiles show small scale (< 5 m relief) topography on the basin floor (Plate 2). Flat, topographically low areas are underlain by laminated sediments that are ponded between till or bedrock ridges. Evidence for subaqueous slumping, in the form of disturbed sediments, is present only in one record; at the base of the south (right hand) slope in profile A - A'.

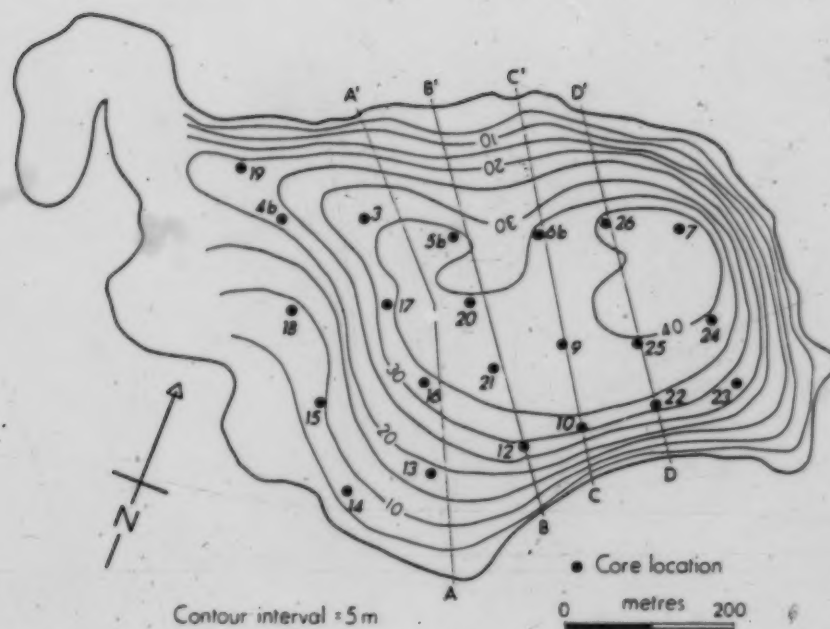
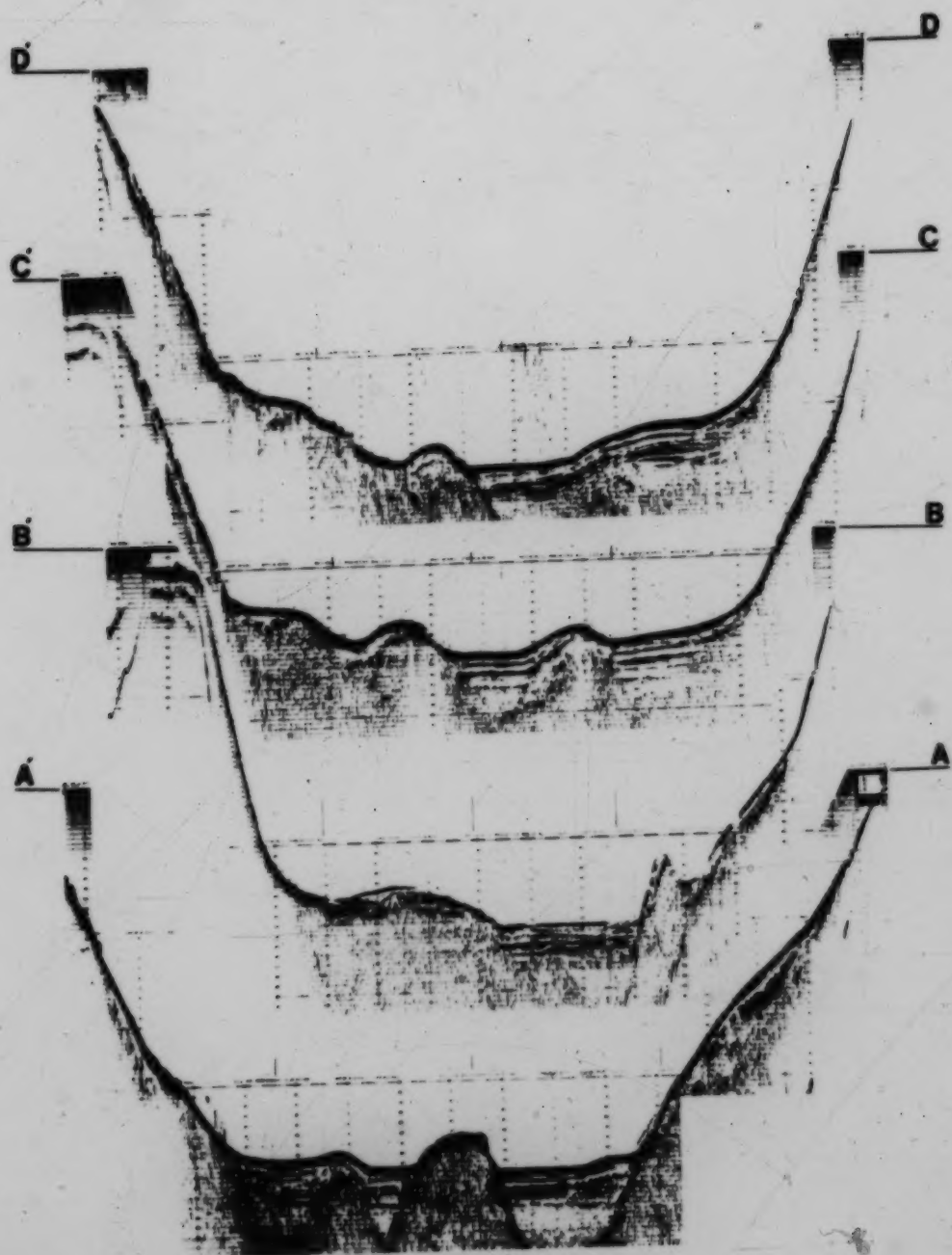


Figure 4-2. Approximate bathymetry of the Lake O'Hara basin. Acoustic profiles and core locations are indicated.

The image shows a large, mostly blank page with faint, diagonal lines and some small dark specks, possibly representing the acoustic profiles mentioned in the caption. The lines are thin and light, running from the top-left towards the bottom-right. There are also some small, dark, irregular marks scattered across the page.

Plate 4-2. Acoustic profiles across the Lake O'Hara basin. Vertical scale: 1 cm = 11 m. Horizontal scale: 1 cm = 75 m. Note the till or bedrock ridges that separate flat, topographically low areas that are underlain by ponded, laminated sediments. Sediments disturbed by slumping are visible adjacent to the basin walls in profile A - A'.



Opabin Lake is an alpine lake located about 2 km south (upvalley) of Lake O'Hara at an elevation of 2280 m (Figure 1 and Plate 1). The surface area of Opabin Lake is approximately 0.013 km and the maximum measured depth 5 m. Meltwater sources for Opabin Lake originate from the Opabin glacier terminus located 500 m to the south. Opabin Lake is bounded on its southern shore by Late Neoglacial moraines (Plate 1). The Lower Cambrian Gog Group accounts for approximately 80% of the bedrock exposed in the upper Cataract Brook Valley, and largely consists of massive, thickly bedded, clean quartzites and sandstones with lesser shale interbeds (Cook 1975). The Middle Cambrian Cathedral and Eldon Formations, consisting of massive limestones and dolomite units, and Stephen and Mt. Whyte Formations, composed largely of shales and thinly - bedded limestones, represent the remaining bedrock exposed in the drainage basin. These Middle Cambrian carbonates and shales are generally confined to elevations of over 2700 m in the study area (Cook 1975).

METHODS

Twenty - two cores, 7.6 cm diameter and up to 257 cm in length, were recovered from Lake O'Hara and Opabin Lake during the winter of 1985. The cores were recovered with a lightweight percussion coring system designed for operation from the ice surface (Reasoner 1936). The core samples were kept frozen inside the plastic core barrels to reduce disturbance during transportation. The core barrels were cut with either a table saw or router and the cores split with

a thin wire. The cores were logged, photographed and subsampled for amino acid analyses, geotechnical properties and pollen analyses immediately after splitting.

Eight cores were selected for amino acid analyses; seven from locations in Lake O'Hara and one from Opabin Lake. Subsamples for amino acid ratio determinations were extracted from the gyttja from four sections of the cored sequence: from coretop, from directly (within 1 cm) below both Bridge River and Mazama tephras, and from directly above the basal contact. A core from Lake O'Hara (LOH25) and a core from Opabin Lake (OPB1) were subsampled at 5 cm intervals for pollen analyses. Six cores were selected and subsampled at approximately 10 cm intervals for water content and wet bulk density determinations. Water contents were determined by dividing the mass of water in a subsample by the mass of oven-dried sediment. Wet bulk densities were measured by determining the mass of a 1 cm³ sediment plug extracted from the core centre. A LECO furnace was used to determine total carbon contents in cores LOH25 and OPB1 (cf. Tabatabai and Bremner 1970). Lower temperature loss on ignition analyses (at 550 °C) conducted on 10 selected samples demonstrated that total carbon content of the sediments is primarily represented by organic carbon.

The tephrostratigraphy of the Upper Cataract Brook Valley was documented by Reasoner and Healy (1986) who confirmed the identities of tephras found in a lacustrine record from Mary Lake (Figure 1). These tephras

were identified as Bridge River tephra and Mazama tephra by electron microprobe analyses of the constituent glass shards. The Bridge River tephra has been dated at approximately 2350 years BP (Mathewes and Westgate 1980), and the age of the the Mazama tephra has been reported as approximately 6800 years BP (Bacon 1983). The tephtras found in the Lake O'Hara and Opabin Lake cores were identified by comparison of field characteristics, as well as features discernable from standard petrographic techniques, with the Mary Lake tephtras. These characteristics included colour, thickness, approximate grain size, glass shard habit, and phenocryst assemblages.

The 32 gyttja subsamples were analyzed to determine aspartic acid D/L ratios using a slight modification of the method outlined in Rutter and Crawford (1984)(see analytical note). D/L ratios of alanine, valine, leucine, phenylalanine, proline, and aspartic acid were routinely determined for the total fraction. Aspartic acid proved to be the most useful because of the relatively fast rate of racemization compared to other amino acids detected in the samples. A minimum of three analyses were performed on each sample and the averages of the D/L ratios of aspartic acid for each sample are reported here.

Basal ^{14}C dates were determined from conifer needles extracted from the lowermost gyttja in two cores from Lake O'Hara (LOH25 and LOH14) and one core from Opabin Lake (OPB1). Needles removed for dating were taken from directly on the basal gyttja/clay contact and only from the undisturbed centres of the cores. Accelerator ^{14}C dating was necessary due to the very small amount of

organic material available for radiocarbon dating.

Acoustic profiles were obtained with a Raytheon RTT - 100A - 1 portable survey system mounted on a small inflatable boat (Shilts *et al.* 1976). The system used a dual low frequency transducer (3.5 and 7.0 kHz) in combination with a high frequency transducer (200 kHz). The power sources for the profiling system and the 1.5 h.p. outboard motor were 12 - volt automobile batteries.

RESULTS

The Lake O'Hara cores comprise two distinct sediment types: gyttja overlying inorganic clastic sediments. A similar stratigraphy is evident in the Opabin Lake cores with the exception that the post-Bridge River interval is represented by massive, light brown silty clays. The basal inorganic sediments are typically rhythmically laminated, alternating light grey (2.5y 7/0) clays, and light to dark grey (2.5y 7/0 - 2.5y 3/0) silts or fine sands (Plate 3). The laminae range in thickness from millimetre scale to a maximum of about 1.5 cm and commonly display normal grading. Less commonly, the basal sediments are light grey (2.5y 7/0), massive fine to medium sand beds that are in excess of 5 cm in thickness. In cores from both lakes, these basal sediments have relatively low water contents (mean: 42.4 %) and high wet bulk densities (mean: 2.67 g/cm³). Total carbon contents of these sediments are relatively low (Figure 3).

The contact separating the gyttja and underlying inorganic sediments is typically sharp, horizontal and appears conformable (Plate 3). A notable

Plate 4-3. Detail of cores LOH25 and LOH3 showing the sharp contact separating overlying gyttja from lower clastic sediments. Note the millimetre to centimetre scale rhythmic laminae in the lower inorganic sediments. In most cases, the contact appears conformable as in core LOH25. Core disturbance in the form of downwarped laminae is visible along the core edge.

LOH25

LOH3

10 cm



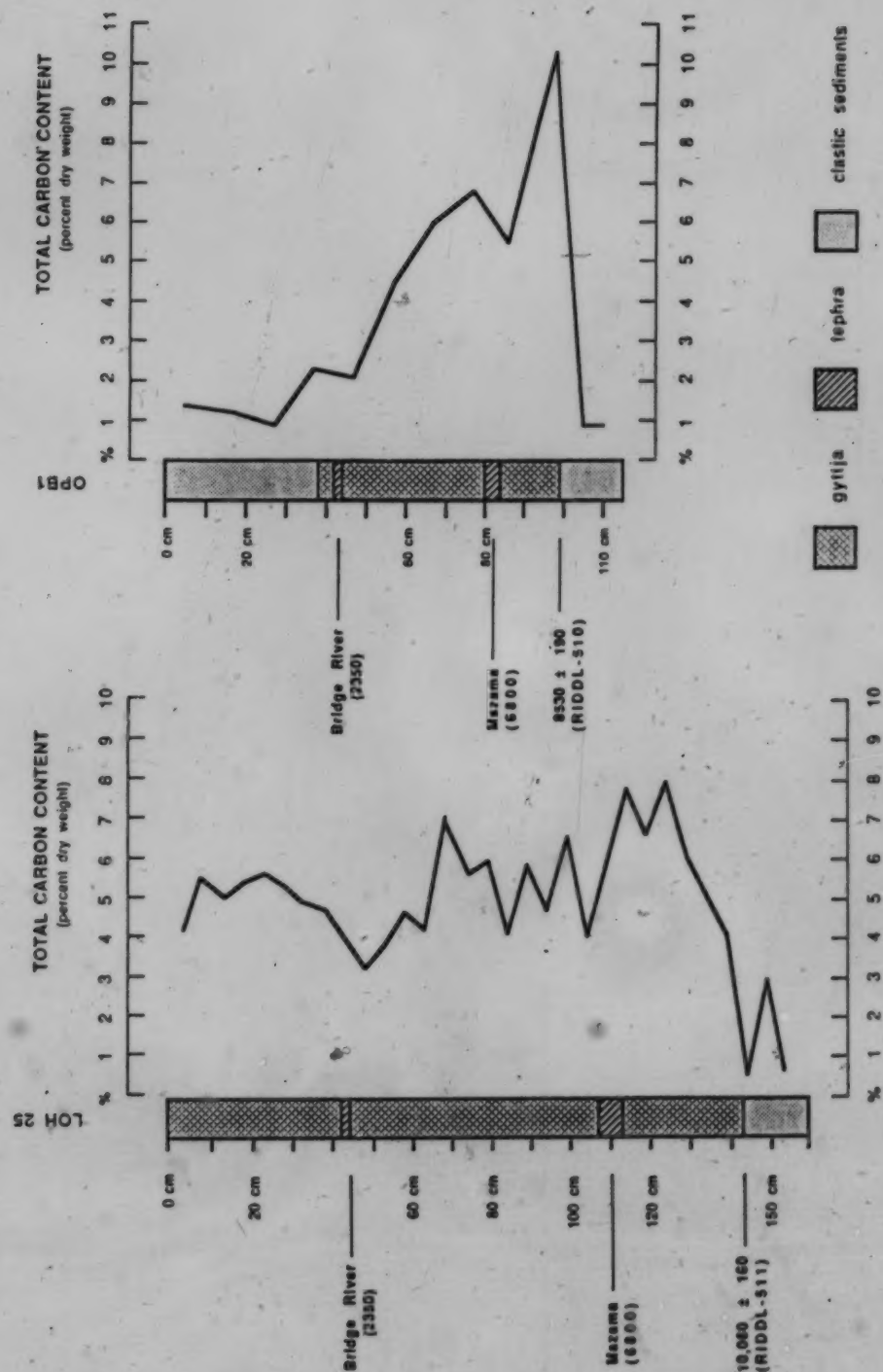


Figure 4-3. Total carbon contents for Lake O'Hara core LOH25 and Opabin Lake core OPB1.

exception is evident in core LOH3 where the contact is undulating and appears to truncate underlying laminae (Plate 3). Core LOH3 was recovered from the base of a slope where the basal sediments may have been disturbed. The contact represents a major division of the sediment types on the basis of sediment colour, total carbon content and geotechnical properties (Plate 3 and Figure 3). The gyttja is of considerably higher water content, higher total carbon content and lower wet bulk density than the underlying clastic sediments.

The gyttja is typically greenish brown (5y 3/2 - 5y 5/3) and is usually massive, or less commonly displays millimetre scale, faint, horizontal laminae. Where present, these laminae usually occur in the lowermost gyttja, directly above the contact with the basal sediments. Large, angular, quartzite and shale clasts are dispersed throughout these sediments. The gyttja in all cores contains both Bridge River and Mazama tephras. The Bridge River tephra is consistently 1.5 to 2.0 cm thick whereas Mazama tephra varies from 5 to 12 cm in thickness. The upper and lower contacts of the two tephras are always sharp and distinct. The Bridge River tephra is commonly almost horizontal, in contrast to the thicker Mazama tephra which commonly shows sloping or undulating contacts within the gyttja. This disturbance is presumably related to sediment loading associated with the heavier Mazama ashfall. Mean water content and wet bulk density values derived from the gyttja are 168.9 % and 1.71 g/cm³ respectively. In both Lake O'Hara and Opabin Lake cores, the interval above the basal clastic sediments and below Mazama tephra typically show the highest water and total

carbon contents and the lowest wet bulk densities. Post-Bridge River sediments in the Opabin Lake record are massive, light brown (5y 5/3) to grey (5y 7/1) silty clays which show lower total carbon percentages, lower water contents, and higher wet bulk densities than the underlying gyttja.

The conifer needle submitted for accelerator ^{14}C dating was identified as *Abies* in the Lake O'Hara core LOH14. Conifer needle fragments in both Lake O'Hara core LOH25 and Opabin Lake core OPB1 were identified as probably either *Abies* or *Picea*. The basal radiocarbon dates derived from the conifer needles extracted from the Lake O'Hara cores LOH14 and LOH25 are $10,100 \pm 200$ (RIDDL - 433) and $10,060 \pm 160$ (RIDDL - 511) years BP respectively. The basal date derived from the Opabin Lake core is 8530 ± 190 (RIDDL - 510) years BP.

Results from amino acid analyses indicate that within the ca. 10,100 year period, there is an overall increase of aspartic acid D/L ratios with increasing age of the sediment (Figure 4 and 5, Table 1). In six cores, LOH3, LOH4b, LOH5b, LOH14, LOH15, and LOH23, all D/L ratios increase consistently with age. Cores LOH23 and LOH5b show increasing D/L ratios with respect to sediment age with the exception of one time interval in each core where ratios decrease slightly (Figure 5). These results are encouraging for a complex substance such as gyttja. Amino acids from the youngest samples would be expected to have undergone little racemization, and show low D/L ratios of ca. 0.07 - 0.08. The slightly higher than expected D/L ratios observed in the modern samples may be

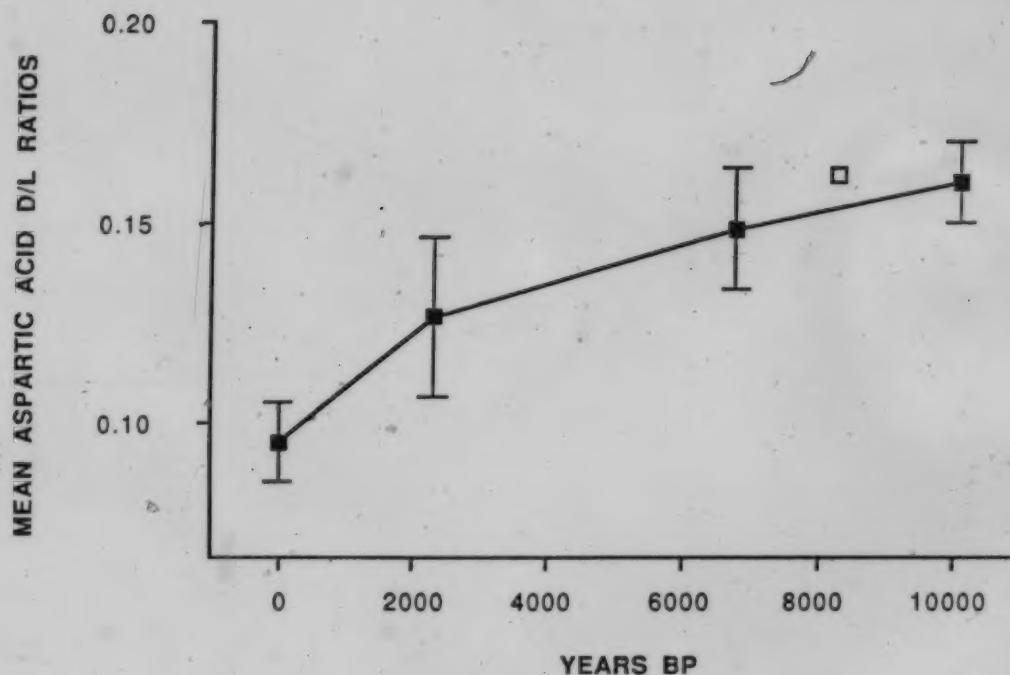


Figure 4-4. Mean aspartic acid ratios representing sediments from the 7 Lake O'Hara cores and Opabin Lake core OPB1. The black squares represent mean values from eight modern, Bridge River and Mazama age samples and seven basal samples from the Lake O'Hara cores (ca. 10,100 years BP). The white square represents the basal sample from the Opabin Lake core (ca. 8530 years BP). Error bars indicate two standard deviations.

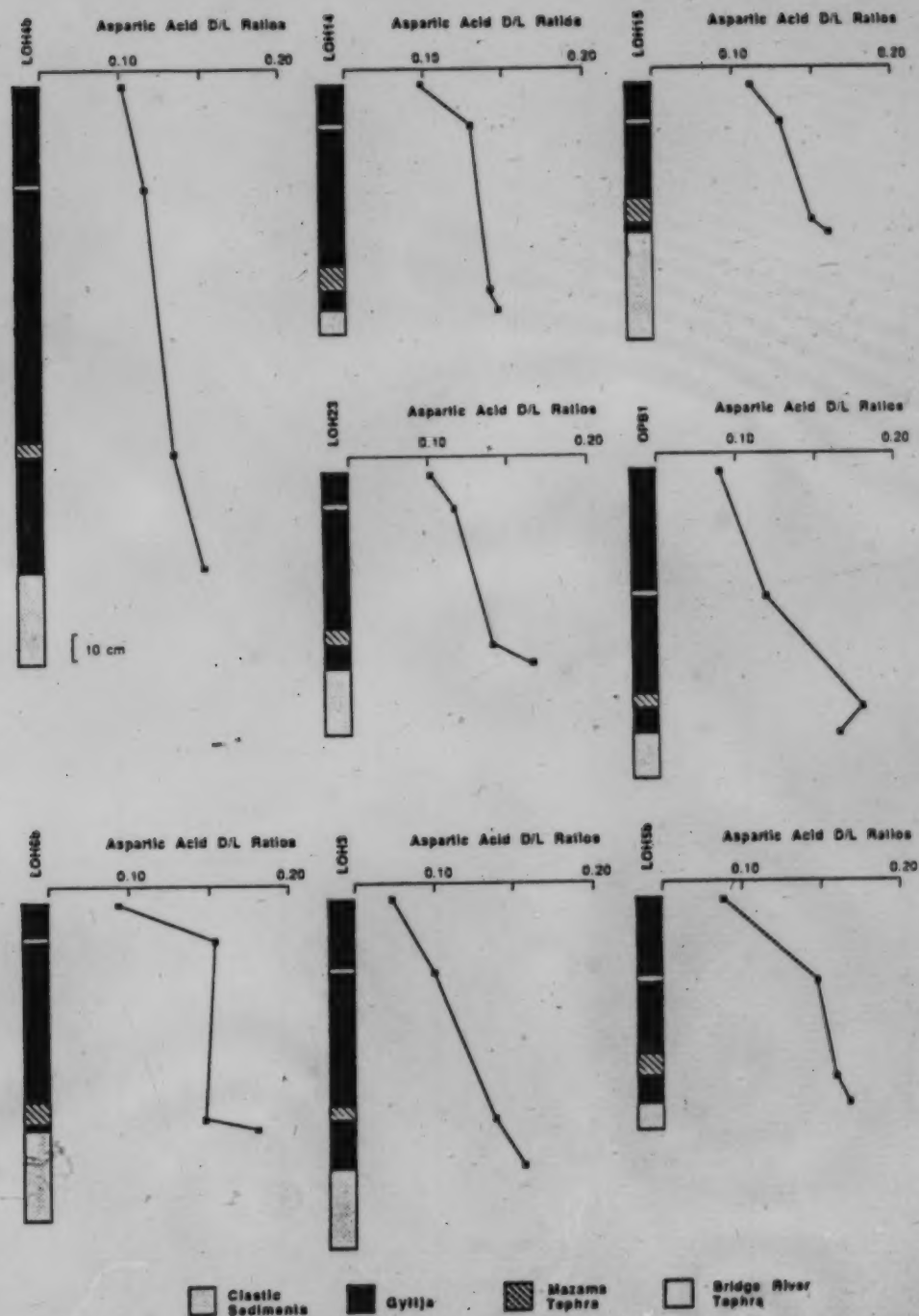


Figure 4-5. Downcore trends in the aspartic acid D/L ratios derived from seven Lake O'Hara cores and one core from Opabin Lake. Standard deviations for this data appear in Table 1.

TABLE 4-1. Aspartic Acid D/L Ratios

core	modern	Bridge				base	σ
		σ	River	σ	Mazama		
LOH3	0.0732	0.0018	0.1007	0.0036	0.1366	0.0066	0.0138
LOH4b	0.1025	0.0033	0.1140	0.0048	0.1314	0.0053	0.0092
LOH5b	0.0882	0.0052	0.1470	0.0042	0.1536	0.0009	0.0017
LOH6b	0.0905	0.0041	0.1543	0.0058	0.1468	0.0037	0.0060
LOH14	0.0969	0.0040	0.1299	0.0028	0.1429	0.0022	0.0033
LOH15	0.1113	0.0024	0.1308	0.0040	0.1497	0.0050	0.0022
LOH23	0.1010	0.0086	0.1156	0.0082	0.1379	0.0130	0.0070
OPB1	0.0860	0.0040	0.1189	0.0118	0.1786	0.0078	0.0130

related to the transformation of amino acids of various ages by circulating waters within the sediments or by the contribution to the sediments of residual organic materials of various ages that originated from soils in the catchment area.

DISCUSSION

The radiocarbon dates of ca. 10,100 years BP from the basal contacts of the Lake O'Hara cores provide the oldest limiting dates for cirque deglaciation in the central Canadian Rocky Mountains. Preliminary pollen and macrofossil data (Reasoner *et al.* 1987) indicate that a *Pinus* - *Abies* forest with lesser *Picea* was established in the vicinity of Lake O'Hara by this time which suggests that the actual timing of deglaciation may have been somewhat earlier. Consequently, the minimum age of the "Late Intermediate" moraine system (Fox 1974; 1979), situated approximately 3 km downvalley from Lake O'Hara, is Late Wisconsinan. This information supersedes the conclusions of Reasoner and Healy (1986) concerning the timing of deglaciation of the upper Cataract Brook Valley.

These basal dates from the Lake O'Hara cores impart considerable constraint on the timing of the deglaciation of the Bow Valley. Although Lake O'Hara is situated on the British Columbia side of the Continental Divide, Fox (1974) proposed, on the basis of geomorphologic features, that ice flowed eastward from the Cataract Brook Valley across Kicking Horse Pass into the Bow drainage. Fox (1974) also tentatively correlated the "Oldest" ice advance in the Cataract Brook Valley, from maximum elevations of glacial features preserved on

the valley walls, with features associated with the Eisenhower Junction advance in the Bow drainage (Rutter 1972).

The basal radiocarbon dates obtained from the Lake O'Hara cores clearly indicate that the tentative limiting date for the retreat of Eisenhower Junction advance ice in the Bow Valley of 9330 ± 170 (GSC - 332) years BP (Rutter 1972) is underestimated. Further, J. M. White (Geological Survey of Canada, personal communication 1987) estimated that ice had receded upvalley from the Eisenhower Junction maxima by ca. 11,500 years BP based on a limiting date of ca. 10,500 years BP from Copper Lake (about 25 km south of Lake Louise). A number of studies have speculated that ice from the Canmore advance (Rutter 1972) was in retreat in the lower Bow Valley between approximately 11,000 and 13,000 years BP (Fedje and White 1986; Kostaschuck and Smith 1983; Jackson 1982; MacDonald 1982; Fergusson and Osborn 1981). Levson and Rutter (1986) have bracketed Late Wisconsinan glaciation from a similar valley setting to the lower Bow Valley in a site in Jasper National Park between ca. 29,100 and 14,900 years BP. Although there is no compelling evidence to suggest otherwise, it remains to be demonstrated that main valley deglaciation in Jasper National Park was synchronous with deglaciation with valleys in the Banff area.

The basal Lake O'Hara dates imply that the speculated timing of deglaciation of the lower Bow Valley is either underestimated, or that Late Wisconsinan ice recession was at least comparable to modern recession rates (e.g., Gardner 1972) determined for glaciers in the Canadian Rockies. Assuming

the estimates for deglaciation of the lower Bow Valley are reasonable (11,000-13,000 years BP), it appears that ice may have receded from the lower valley to well within high cirques near the Continental Divide during a period of ca. 1000 to 3000 years. Based on a review of paleobotanical studies conducted in western Canada, Vance (1986) suggested that warmer and drier conditions prevailed during the late glacial and early Holocene, which is consistent with the possible rapid Late Wisconsinan deglaciation of the Bow Valley. Paleoclimatic reconstructions for this period, however, are hampered by the presence of pollen records with no modern analogues and by the influence of migration rates of vegetation on the pollen record (Vance 1986).

The sharp contact separating the basal inorganic sediments from the overlying gyttja represents a significant change in the style of sedimentation in the Lake O'Hara basin at ca. 10,100 years BP. A possible explanation for the origin of this contact involves the entrapment of clastic sediments in upvalley lake basins as they are deglaciated (Smith 1981; Leonard 1981). Under these circumstances, variations in pollen concentration, and consistent composition of pollen taxa would be expected from pollen spectra that span the contact. In contrast, preliminary palynological results (Reasoner *et al.* 1987) show a compositionally distinct pollen assemblage for the basal sediments that is dominated by *Pinus*, *Artemisia* and Gramineae and includes the "long-distance" taxa *Quercus*, and *Ephedra*. It is therefore presumed that the basal contact represents reduced clastic sedimentation associated with the post glacial

stabilization of the landscape by vegetation in the vicinity of Lake O'Hara.

Mean annual sedimentation rates for 14 Lake O'Hara cores were calculated directly from sediment thickness data for the ca. 10,100 years BP - Mazama, the Mazama - Bridge River and the post - Bridge River time periods (Table 2). A difference of only 40 years between the two basal dates, obtained from widely separated core sites in the O'Hara basin, suggests that the basal gyttja/clay contact in the Lake O'Hara cores can be used as a chronostratigraphic marker. Similar data were obtained from the 2 Opabin Lake cores with the exception that the oldest total sedimentation rates represent the period ca. 8530 years BP - Mazama time (Table 2). Although extremely easy to derive, total sedimentation rate data is probably not as accurate as clastic sediment influx as a proxy indication of upvalley ice activity.

Despite considerable variation in the Lake O'Hara data, mean annual sedimentation rates are consistently lower for the 10,100 years BP - Mazama interval than for the post - Mazama period. Averaged total sedimentation rate values derived from the 14 Lake O'Hara cores that penetrated the three dated horizons are 0.13 mm/yr (post - Bridge River), 0.13 mm/yr (Mazama - Bridge River) and 0.05 mm/yr (10,100 years BP - Mazama). Averaged total sedimentation rate values derived from the 2 Opabin Lake cores are 0.19 mm/yr (post - Bridge River), 0.07 mm/yr (Mazama - Bridge River) and 0.06 mm/yr (8530 years BP - Mazama). Increasing down core trends in wet bulk densities and decreasing down core trends in water contents were not evident in the gyttja

TABLE 4-2. Sedimentation Rate Data (mm/yr)

core	post-Bridge		Mazama -	
	River	Bridge River	base-Mazama	
LOH3	0.11	0.12	0.06	
LOH4b	0.16	0.22	0.13	
LOH5b	0.13	0.06	0.03	
LOH6b	0.06	0.14	0.01	
LOH7	0.18	0.17		
LOH9	0.08	0.10	0.03	
LOH10	0.29	0.15		
LOH12	0.14	0.16	0.09	
LOH13	0.16	0.18	0.02	
LOH14	0.07	0.12	0.03	
LOH15	0.06	0.05	0.01	
LOH16	0.27			
LOH17	0.23	0.10		
LOH19	0.25	0.17	0.05	
LOH21	0.17	0.10	0.09	
LOH22	0.19			
LOH23	0.06	0.10	0.02	
LOH24	0.09			
LOH25	0.19	0.14	0.09	
LOH26	0.12	0.16	0.05	
mean	0.13	0.13	0.05	
OPB1	0.20	0.09	0.04	
OPB3	0.17	0.04	0.07	
mean	0.19	0.07	0.06	

Notes: Mean values determined from cores penetrating all 3 dated horizons. LOH - Lake O'Hara; OPB - Opabin Lake.

indicating that post - depositional consolidation has not significantly influenced the derived sedimentation rates.

The basal inorganic sediments from Lake O'Hara and Opabin Lake did not provide any material suitable for radiocarbon dating. Consequently, the time significance of the rhythmic laminae common in these basal sediments cannot be determined. If the laminae are annual (varves), total sedimentation rates for this interval are of the order of one to several millimetres per year, which are at least an order of magnitude greater than sedimentation rates determined from the overlying gyttja.

Leonard (1986a, 1986b) suggested that Holocene sedimentation rates in Bow, Hector, and Crowfoot lakes were significantly influenced by regional glacial/climatic conditions. Relatively high sedimentation rates occur during, and up to a century following, periods of increased upvalley ice extent (Leonard 1986a). In both the Lake O'Hara and Opabin Lake records, periods of low total sedimentation rates are represented by sediments of high carbon content (Figure 3). Conversely, material representing the highest total sedimentation rates show relatively low carbon content. This suggests that total sedimentation rate data are at least approximately proportional to clastic sediment input in the Lake O'Hara and Opabin Lake records.

The Crowfoot Lake record provided by Leonard (1986b, 1987) and the Opabin Lake record are strikingly similar. Both records indicate that relatively high total sedimentation rates prevailed during the post - Bridge River period

whereas low total sedimentation rates characterize the mid - Holocene. These late Holocene elevated sedimentation rates are presumably related to climatic conditions associated with more extensive upvalley ice during the last 2000 - 3000 years BP. Based on downcore extrapolation from the Mazama tephra, Leonard (1987) reported evidence for high glacial output shortly before 9000 years BP in the Crowfoot Lake record and suggested the possibility that these sediments may be related to the Crowfoot Advance. In the Crowfoot Lake record, these sediments are directly overlain by organic sediments associated with the onset of the mid-Holocene period of increased warmth and reduced ice extent (Leonard 1987). The shift to primarily organic sedimentation in Opabin Lake occurred at ca. 8350 years BP.

In the Lake O'Hara records, the Mazama - Bridge River total sedimentation rates and the post - Bridge River total sedimentation rates are relatively consistent whereas the Opabin Lake record and the lacustrine records provided by Leonard (1986b, 1987) indicate that significantly higher total sedimentation rates represent the late Holocene. The lowest Lake O'Hara total sedimentation rates are represented by the 10,100 years BP - Mazama interval. An attractive explanation for the discrepancy between these records is that the glacial signal from limited ice advances such as the Cavell or Crowfoot was not registered in Lake O'Hara due to the trapping of clastic sediments in upstream lakes.

Of perhaps greater significance is the large variability in total

sedimentation rates derived from the Lake O'Hara cores (Figure 6). For example, post - Bridge River and Mazama - Bridge River sedimentation rates in core LOH4b are 0.16 and 0.22 mm/yr respectively. In sharp contrast, post - Bridge River sedimentation rates are 0.29 mm/yr and Mazama - Bridge River sedimentation rates are 0.15 mm/yr in core LOH10. Core LOH10 is located proximal to an inflowing stream and core LOH4b is situated closer to the lake outlet. The sedimentary records obtained from the Lake O'Hara basin clearly demonstrate that downcore total sedimentation rate data vary considerably with core location. Consequently, the use of total sedimentation rate data, from any single Lake O'Hara core, as a proxy record of upvalley glacial activity is highly suspect.

Glacial stream systems feeding Bow, Hector, Crowfoot and Opabin Lakes are not interrupted by several upstream lake basins as is the case with Lake O'Hara. As noted above, it is possible that the influence of glacial activity is not well represented in lacustrine records where inflowing glacial stream systems have passed through one or more upvalley lakes. Consequently, the use of total sedimentation rate data as a tool for understanding glacial chronologies may be valid only when obtained from lakes that have been fed by stream systems originating directly from glaciers.

The results of amino acid analyses indicate that within the ca. 10,100 year time span, increases of D/L ratios with age can be detected from bulk gyttja samples. Before gyttja can be used independently as a relative age dating tool,

LAKE O'HARA SEDIMENTATION RATES (mm/yr)

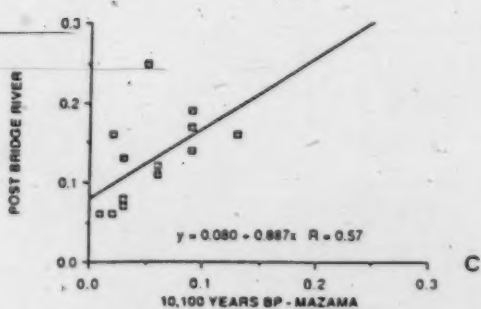
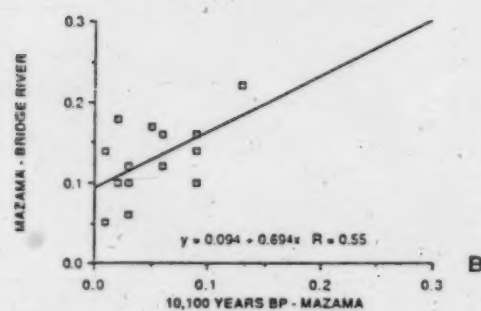
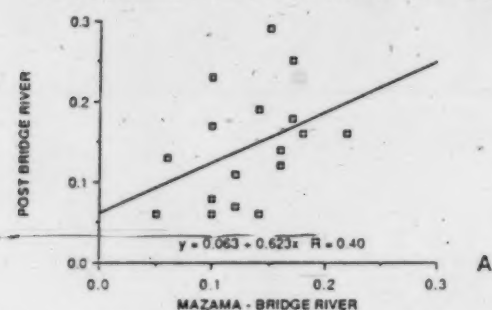


Figure 4-6. Comparison of sedimentation rate data from the Lake O'Hara cores. Note the high degree of variability in the data, particularly between post - Bridge River and Mazama - Bridge River sedimentation rates (A).

or an estimate of absolute age with confidence, much more information on the character of the basic substance and diagenetic changes that can take place upon burial must be explained. For example, kinetic studies, quantifying the derivation, amounts, varieties, and racemization rates of amino acids are needed. Analytical methods are hampered by mineral and organic impurities that are difficult to remove during sample preparation. These impurities may include non-protein material that have the same characteristics as protein amino acids. Gyttja can absorb contaminants such as bacteria, fungi, and molds or lose material through leaching. In addition, D - aspartic acid is commonly produced by bacteria (Pollack *et al.* 1977).

The fact remains however, that an increase of D/L ratios with increasing sediment age was detected in the present study. The results suggest that aspartic acid D/L ratios, derived from bulk gyttja samples, may be useful in cases where chronostratigraphic markers are absent to detect the presence of significantly disturbed or reworked sediments. The ratios show insufficient variation over the extent of the Holocene to be of use for correlating horizons and estimating relative sedimentation rates between cores (Figure 4).

CONCLUSIONS

- (1) The basal radiocarbon dates from the Lake O'Hara cores indicate that Bow Valley ice had receded to within cirques situated adjacent to the Continental Divide prior to ca. 10,100 years BP. The minimum age of moraine systems

located downvalley from Lake O'Hara is therefore Late Wisconsinan.

(2) The use of total sedimentation rate data as a proxy record of upvalley ice extent (Leonard 1986a, 1986b) indicates that a period of minimal glacial influence prevailed in the Opabin Lake basin from ca. 8530 years BP - Bridge River period. Mean annual sedimentation rates derived from ca. 8530 years BP - Mazama and Mazama - Bridge River sediments from Opabin Lake cores are on the order of 0.06 - 0.07 mm/yr whereas post Bridge River sedimentation rates are generally higher (0.19 mm/yr).

(3) Highly variable total sedimentation rate data obtained from Lake O'Hara cores suggest that the focus of sedimentation in the O'Hara basin has shifted considerably during the Holocene. Consequently, the use of total sedimentation rate data as a proxy record of upvalley glacial activity is inappropriate in the Lake O'Hara setting where the inflowing glacial stream systems are interrupted by upvalley lake basins.

(4) Aspartic acid D/L ratios obtained from Holocene bulk gyttja subsamples, in all but two cases, increase consistently with respect to sediment age. The data do not permit confident correlation between cores or estimates of absolute age based on D/L ratios. However, the downcore trends in the D/L ratios suggest the possibility of using quantitative amino acid data from bulk gyttja samples to detect the influence of significant reworking in Holocene records where chronostratigraphic markers are absent.

ANALYTICAL NOTE

In the initial analyses for D/L ratios of amino acids, the D/L ratios of aspartic acid did not show the consistency of ratio increase with increasing sediment age as was achieved with the results presented here. Although the basic method as outlined in Rutter and Crawford (1984) was used in the initial analyses, the better results were obtained by increasing the amount of sample analyzed from 1 g to 4 g, and by rinsing the sample during desalination by using 30% isopropanol/H₂O (ph 4.5) instead of using only water. The change in method resulted in better peak resolution. The amino acid peaks were significantly larger in proportion to the interference peaks and, consequently, the relative amount of error introduced was not as great. This initial interference seemed to occur primarily with the D - peaks.

The amino acid laboratory at the University of Alberta is laboratory H of the Wehmiller (1984) interlab comparison. Recent analyses of the standards yielded the following D/L aspartic ratios; ILC - A = 0.3438; ILC - B = 0.6678.

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CHAPTER 5

LATE QUATERNARY ENVIRONMENTAL CHANGE IN THE LAKE O'HARA REGION, YOHO NATIONAL PARK, BRITISH COLUMBIA †

† A version of Chapter 5 has been submitted to: *Palaeogeography*,
Palaeoclimatology, *Palaeoecology*.

INTRODUCTION .

During the last decade, an increasing number of studies have focussed on the reconstruction of Late Quaternary environments of Western Canada and adjacent areas in the United States. The majority of these works are based on palynological studies and have concentrated on the Alberta plains and foothills, the southwest Yukon-southeast Alaska region, and the southern British Columbia-northern Washington-Idaho area (reviews by Vance 1986; Mehringer 1985; Baker 1983; Schweger 1982). However, relatively little palaeoenvironmental data has been obtained from the central Canadian Rocky Mountains. Holocene pollen and macrofossil records from Jasper National Park are documented by Luckman and Kearney (1986), Kearney and Luckman (1987, 1983a, 1983b, 1981). Beaudoin (1984; 1986) outlined a ca. 9600 year pollen record from Wilcox Pass near the Banff-Jasper National Park boundary. Both Beaudoin (1986) and Luckman and Kearney (1986, 1983b) used pollen ratios obtained from alpine records to document timberline displacements during the Holocene. MacDonald (1982) and Fergusson (1978) document pollen records from montane forest settings in the Kananaskis and Elk valleys respectively.

This study provides a palaeoenvironmental reconstruction for the subalpine-alpine upper Cataract Brook Valley, based on a combination of pollen and macrofossil data. These data were derived from continuous sediment cores recovered from subalpine Lake O'Hara and alpine Opabin Lake (Figure 1). Adjacent alpine and a subalpine lakes were selected for study in order to, (1)

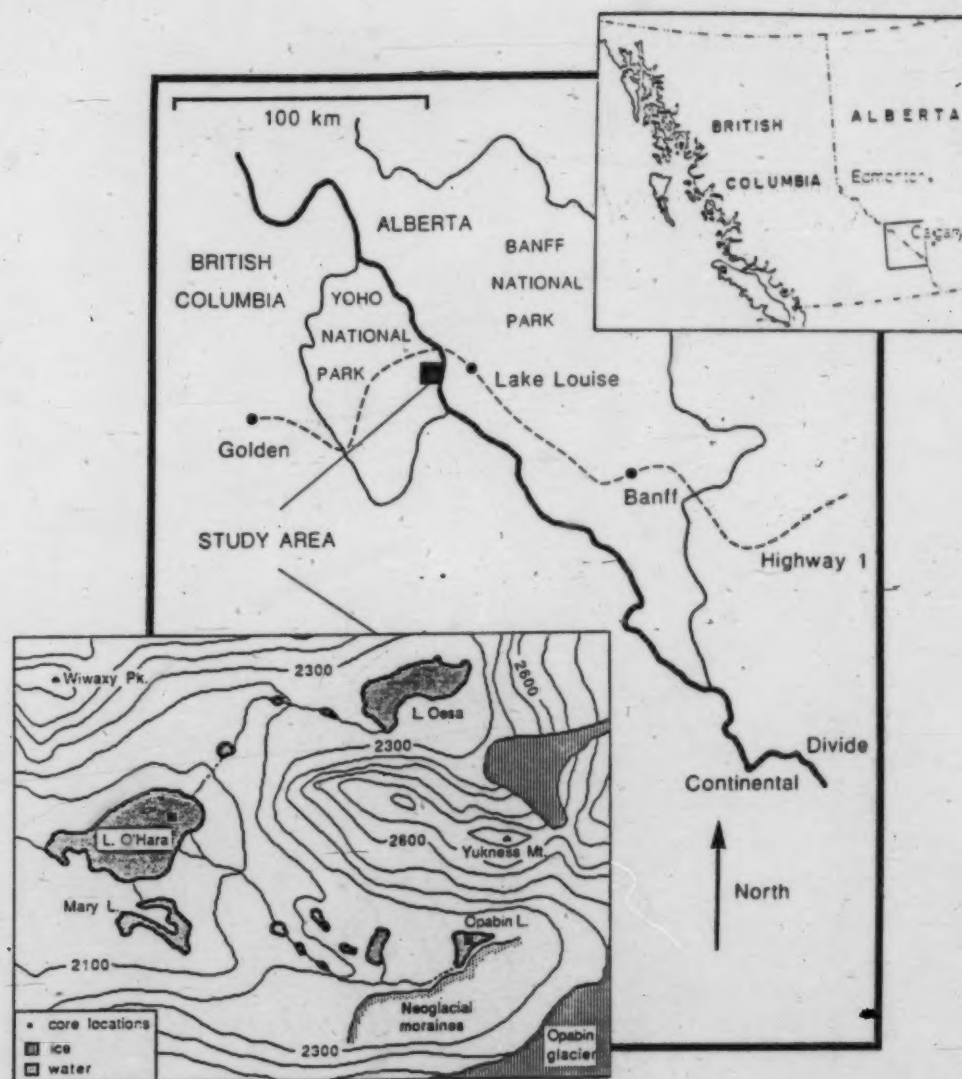


Figure 5-1. Regional map of the Central Canadian Rocky Mountains showing the location of the study area.

document the Late Quaternary vegetational history of the upper Cataract Brook Valley, (2) compare the palaeoenvironmental records obtained from adjacent lakes which span the modern timberline ecotone by 230 m in elevation, and (3) record the up-slope and down-slope displacement of the climatically sensitive timberline ecotone during the Holocene.

Physiography

Subalpine Lake O'Hara and alpine Opabin Lake are situated in the upper Cataract Brook Valley (latitude 51° 21'N, longitude 116° 20'W) directly west of the Continental Divide in Yoho National Park, British Columbia (Figure 1). Local relief in the upper Cataract Brook drainage is considerable, with elevation gains of 1300 m within 2 km of Lake O'Hara. The lakes are located in the Lake Louise group of peaks, many of which exceed 3000 m in elevation and host one or more small alpine glaciers.

Lake O'Hara is situated at an elevation of 2015 m above sea level (asl). The surface area of Lake O'Hara is approximately 0.5 km² and the maximum measured depth 42 m. Two of the principal inflowing streams entering Lake O'Hara originate from glacial sources less than 3 km distant in the Oesa and Opabin cirques (Figure 1 and Plate 1). The third stream drains from Mary Lake, which is presently not fed by glacial streams.

Opabin Lake is situated at an elevation of 2280 m asl, approximately 2 km south (upvalley) from Lake O'Hara. The surface area of Opabin Lake is about



Plate 5-T. Aerial photograph of the study area showing the locations of Lake O'Hara (loh), Opabin Lake (opb), Late Neoglacial moraines (ln), "Late Intermediate" moraines (li), and present glaciers (g).



0.013 km² and its maximum measured depth is 5 m. Opabin Lake is situated approximately 500 m north (downvalley) from the terminus of the Opabin Glacier which is the principal source of water to the Lake.

Geology

The Lower Cambrian Gog Group, composed of quartzites and associated shales, outcrops extensively in the vicinity of both Lake O'Hara and Opabin Lake (Cook 1975). Middle Cambrian carbonates and shales of the Mount Whyte, Cathedral, Stephen and Eldon Formations outcrop at elevations generally above 2700 m on the surrounding peaks.

Lake O'Hara is situated approximately midway between Neoglacial moraines and moraines attributed to the "Late Intermediate" ice advance of Fox (1979; 1974). Opabin Lake is bounded on its southern shore by Late Neoglacial moraines (Figure 1 and Plate 1). In general, the most extensive Neoglacial ice advances occurred in the Rocky Mountains during the early 18th and mid-late 19th centuries (Luckman 1986; Luckman and Osborn 1979). Reasoner *et al.* (1987) demonstrated that the minimum age of the "Late Intermediate" moraines is Late Wisconsinan (Plate 1).

Modern vegetation and climate

Lake O'Hara is situated in the lower subalpine vegetation zone as defined by Goen and Kuchar (1982). The local vegetation is dominated by *Abies*

lasiocarpa (subalpine fir) and *Picea engelmannii* (Engelman spruce) with *Larix lyallii* (subalpine larch) and *Pinus albicaulis* (whitebark pine) present at elevations near timberline. Typical understory components include *Menziesia ferruginea* (menziesia), *Cornus canadensis* (bunchberry), *Vaccinium scoparium* (grouseberry), and *Linnaea borealis* (twinline) (Coen and Kuchar 1982). *Alnus crispa* (= *A. sinuata*) (green alder) is common on several avalanche paths that intersect the northern shore of the lake.

The higher elevation Opabin Lake site is situated in the heath tundra zone of Coen and Kuchar (1982). Alpine vegetation in the area is diverse and locally highly variable, but usually includes *Carex* spp. (sedge), *Anemone occidentalis* (western anemone), *Phyllodoce glanduliflora* (yellow heather), *Artemisia norvegica* (alpine wormwood), *Cassiope mertensiana* (white heather), *Silene acaulis* (moss campion), *Potentilla* spp. (cinquefoil), *Dryas octopetala* (white dryad), and *Salix* spp. (willow) (Coen and Kuchar 1982).

The alpine timberline belt is situated between Lake O'Hara and Opabin Lake spanning the zone from approximately 2100 m to 2300 m asl. The upper elevation of continuous forest, or the forest limit (Arno and Hammerly 1984), occurs slightly above the lower lip of the Opabin Cirque at an elevation of approximately 2130 m asl. Isolated krummholz mats occur at, and slightly above, the elevation of Opabin Lake. The position of timberline in the region is probably associated with the elevation of the July 10° isotherm (Wardell 1974; Tranquillini 1979).

Longterm climatic data for the region are available from Field, British Columbia, situated approximately 10 km northwest of the study area at an elevation of 1280 m asl. The mean annual temperature at Field is 2.2° C and the mean July temperature approximately 15° C (Janz and Storr 1977). Total annual precipitation at Field is about 580 mm/yr of which about 42% is represented by snowfall (Janz and Storr 1977). Estimated mean July temperatures for Lake O'Hara and Opabin Lake are 11.2° C and 10.0° C respectively based on a lapse rate of 0.5° C/100 m (Hrapko and LaRoi 1978). Using the approximate regression equations for average annual precipitation as a function of elevation (Janz and Storr 1977), annual precipitation in the upper Cataract Brook Valley is probably on the order of 890 mm/yr.

METHODS

Core sampling was conducted on Lake O'Hara and Opabin Lake during February and March of 1985. Twenty-two 7.6 cm diameter cores were recovered using a portable percussion coring system designed for operation from the ice surface (Reasoner 1986). Two cores, LOH25 and OPB1, recovered from the deepest part of Lake O'Hara and Opabin Lakes respectively, were selected for pollen and macrofossil analyses (Figure 1). The core samples were kept frozen in their plastic core barrels to reduce disturbance during transportation. The cores were logged, photographed and subsampled for pollen and total carbon analyses immediately after splitting.

Chronologic control for the two cores was provided by accelerator radiocarbon dates from basal organic material and the identification of well dated tephras in the records. The radiocarbon dates were obtained from conifer needles and conifer needle fragments extracted from the centres of the cores directly (< 1 cm) above the contact with basal inorganic sediments. The tephrostratigraphy of the Upper Cataract Brook Valley was documented by Reasoner and Healy (1986) who confirmed the identities of tephras found in a lacustrine record from Mary Lake (Figure 1). These tephras were identified as Bridge River tephra and Mazama tephra by electron microprobe analyses of the constituent glass shards. The tephras found in the Lake O'Hara and Opabin Lake cores were identified by comparison of field characteristics, as well as features discernable from standard petrographic techniques, with the Mary Lake tephras. These characteristics included colour, thickness, approximate grain size, glass shard habit, and phenocryst assemblages.

Pollen analyses were conducted on 1 cm^3 sediment subsamples taken at 5 cm intervals from both LOH25 and OPB1 cores. Pollen samples were processed following the procedure of Faegri and Iversen (1975) with the addition of *Lycopodium* marker grains (Stockmarr 1971) prior to the initial suspension in concentrated HCl. The addition of a heavy liquid separation to the procedure, to remove clastic sediments, had little effect on the gyttja subsamples from the Lake O'Hara core. Consequently, the procedure was only used on the subsamples extracted from the inorganic intervals of the Opabin Lake core. The

palynomorphs were identified and counted, under 400 and 600 power magnification, using the pollen reference collection of the Department of Anthropology, University of Alberta. Pollen sums (excluding spores and marker grains) generally exceeded 600 in LOH25 samples and 400 in OPB1 samples. Relative percent pollen diagrams, showing total pollen concentration data and sediment stratigraphy, were constructed for cores LOH25 and OPB1 and zoned by visual inspection.

Where possible, *Pinus* pollen was identified to either *Haploxylon* or *Diploxylon* subgenera based on the presence or absence of a verrucate distal membrane. *P. contorta* is the only diploxylon pine presently inhabiting the central Canadian Rocky Mountains (Moss 1983) and is the likely source for much of the diploxylon pine pollen in the Lake O'Hara and Opabin Lake records. Subgenus *Haploxylon* is represented by two species of pine that may have contributed haploxylon pine pollen to the records. Although *P. albicaulis* is the only haploxylon pine presently occurring in Yoho National Park, *P. flexilis* is also present in the region (Moss 1983). Due to the difficulty in differentiating *Larix* and *Pseudotsuga* pollen, these pollen types have been grouped together as *Larix/Pseudotsuga*.

Conifer needles for macrofossil analyses were concentrated by soaking approximately 10 cm thick subsamples of cores LOH25 and OPB1 in a 15% NaOH solution and wet sieving the sediments through a 250 mesh sieve. The conifer needles were then identified with reference to modern specimens and

counted under a 40 power dissecting microscope. *Pinus* needles were subdivided into *Pinus* cf. *contorta* and *Pinus* cf. *albicaulis/flexilis* types. Macrofossil diagrams representing both the LOH25 and the OPB1 records were constructed to show the total numbers of needles and needle fragments.

Total carbon content values were determined using a LECO furnace (Tabatabai and Bremner 1970). Lower temperature loss on ignition analyses (550° C), conducted on 10 selected subsamples, demonstrated that total carbon content is primarily represented by organic carbon.

RESULTS

Core description and Geochronology

Core LOH25 contains both Bridge River and Mazama tephras within massive, greenish-brown gyttja that overlies grey, rhythmically laminated, basal inorganic sediments (Figure 2). The Bridge River tephra has been dated at approximately 2350 years BP (Mathewes and Westgate 1980), and the age of Mazama tephra has been reported as approximately 6800 years BP (Bacon 1983). The contact separating the gyttja and underlying inorganic sediments is typically sharp, horizontal and appears conformable. The gyttja is of considerably higher total carbon content than the underlying clastic sediments (Figure 2). A similar stratigraphy is evident in the Opabin Lake core with the exception that the post-Bridge River interval is represented by massive, light brown silty clays that show total carbon contents that are similar to values for the

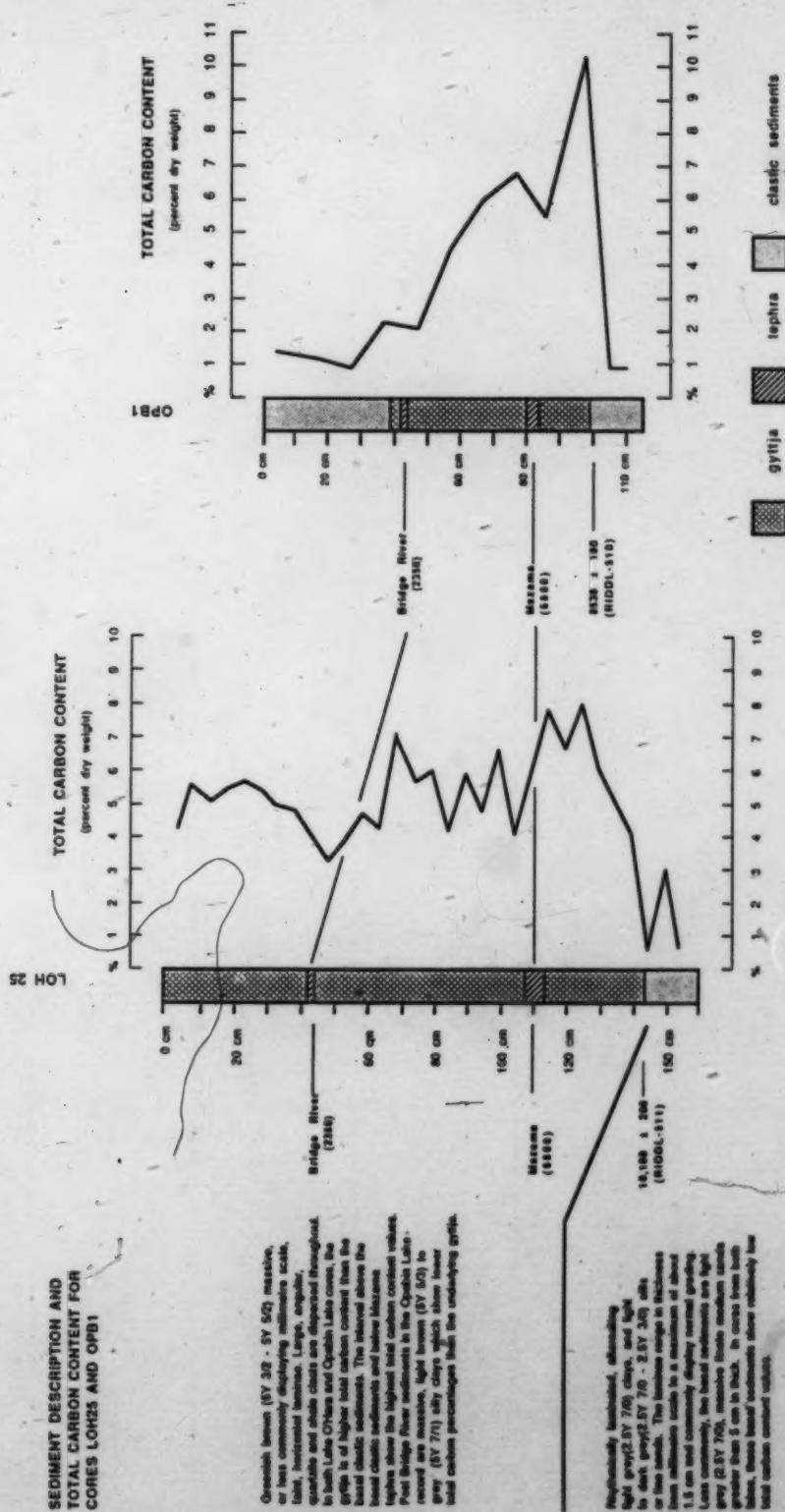


Figure 5-2. Total carbon contents and sediment descriptions for cores LOH25 and OPB1.

basal inorganic sediments in the core (Figure 2).

Radiocarbon dates were obtained from conifer needles and conifer needle fragments. An accelerator ^{14}C date of $10,060 \pm 160$ years BP (RIDDL-511) from the basal gyttja/clay contact in core LOH25 indicates that the core represents the entire Holocene record. A similar basal date of $10,100 \pm 200$ years BP (RIDDL-433) was obtained from the same horizon in another Lake O'Hara core (LOH14). The accelerator ^{14}C date obtained from the basal gyttja/clay contact in the Opabin Lake core is 8530 ± 190 years BP (RIDDL-510).

Lake O'Hara palaeobotanical data (Figure 3 and Figure 4)

LOH25 Zone 1, 160-142 cm. Pinus-Artemisia assemblage zone.

LOH25 Zone 1 predates 10,100 years BP. Zone 1 is dominated by *Pinus* pollen, which represents 74%-88% of the spectrum. Haploxylon/diploxylon ratios indicate the pine pollen is primarily diploxylon type. *Artemisia* and Gramineae (grasses) pollen range from 1%-7% and from 0.5%-4% respectively. *Alnus*, *Picea* and *Abies* pollen are present in percentages below 4%. Traces of the "long distance" taxa *Quercus* (oak) and *Ephedra* (Mormon tea) are present only in this zone (< 2%). Traces (< 1%) of high spine-Tubuliflorae (composite subfamily) and *Shepherdia canadensis* (soapberry) pollen are also present. With the exception of *Selaginella densa* (little clubmoss), spores are absent from this zone. Total pollen concentrations are very low in this zone, varying from 1.3×10^3 - 3.7×10^3 grains/cm³. The upper zone boundary is marked by an

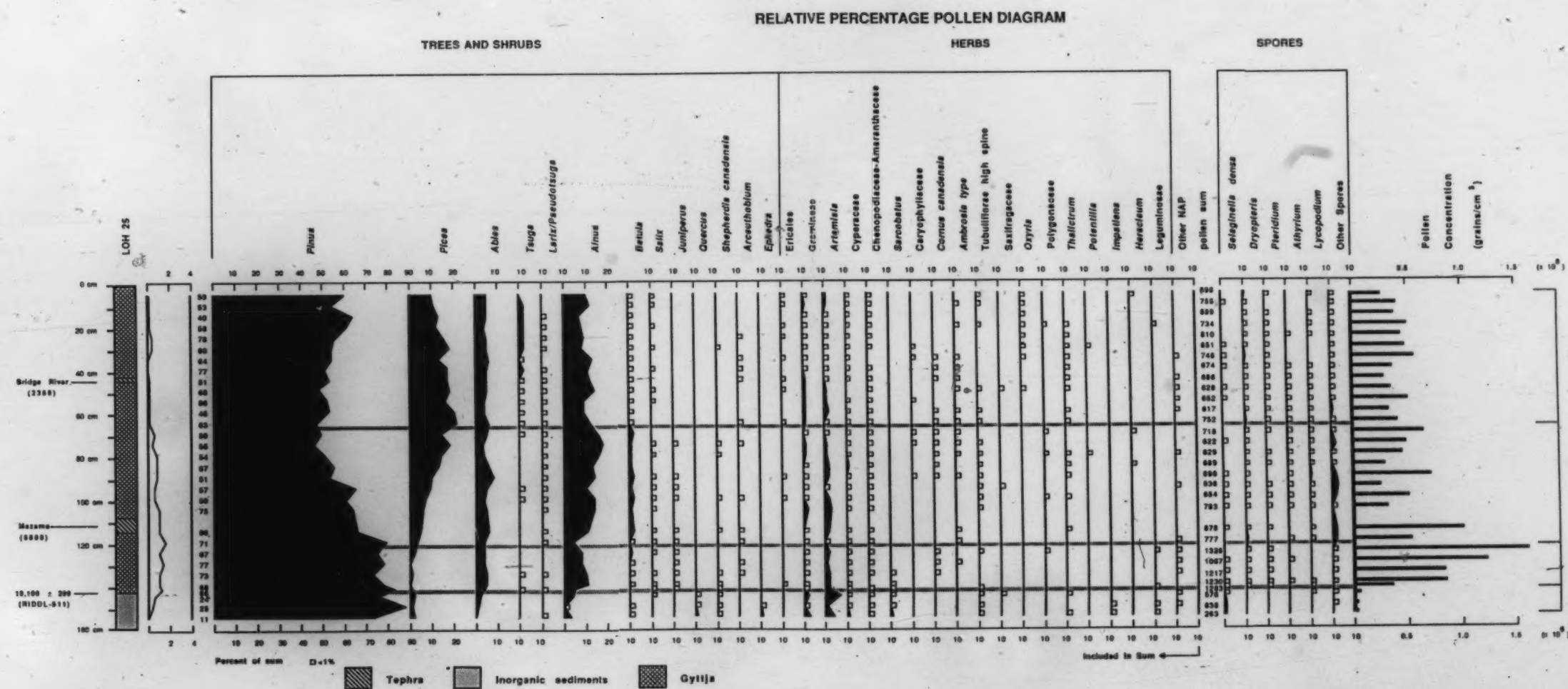


Figure 5-3. Pollen diagram from core LOH25, Lake O'Hara.

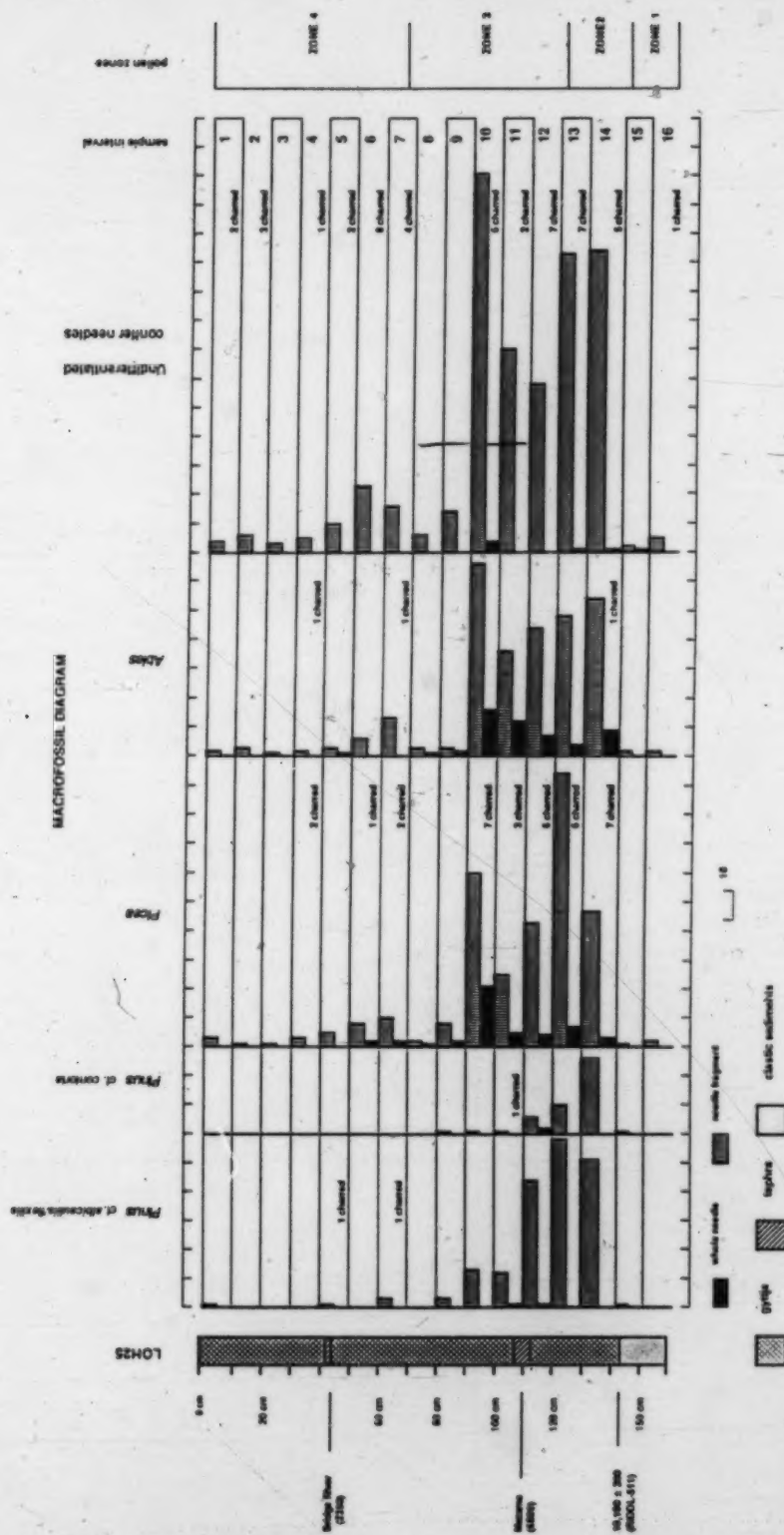


Figure 5-4. Macrofossil diagram from core LOH25, Lake O'Hara.

abrupt increase in *Abies* and *Alnus*, accompanied by decreases in *Artemisia* and Gramineae pollen percentages. Only a few fragments of *Picea*, *Abies*, *Pinus* cf. *albicaulis/flexilis* and *Pinus* cf. *contorta* needles were identified from sediments representing this interval.

LOH25 Zone 2, 142-122 cm. Pinus-Alnus assemblage zone.

LOH25 Zone 2 dates from 10,100 years BP to an extrapolated age of ca. 7000 years BP. *Pinus* pollen percentages remain high throughout this zone (about 75%) although, in contrast to Zone 1, haploxylon pine pollen is dominant. *Alnus* and *Abies* pollen percentages range from 4%-5% and from 5%-11% respectively. *Picea* pollen percentages remain low (near 1%) throughout the zone. *Artemisia* and Gramineae pollen are also present in low percentages. Zone 2 marks the first appearances of, *Arceuthobium* (Pine dwarf mistletoe), Ericales (Heath family), *Cornus canadensis*, Polygonaceae (buckwheat family), and *Juniperus* (juniper) type pollen as well as *Dryopteris* (shield fern), *Pteridium* (bracken) and *Athyrium* (lady fern) spores. Pollen concentrations rise to 1.6×10^6 grains/cm³, the highest observed in the Lake O'Hara record. The upper boundary of LOH 25 Zone 2 is placed at the shift from relatively constant to steadily increasing *Picea* pollen percentages accompanied by a sharp decline in *Pinus* pollen percentages. An abrupt increase in the number of identified needles occurs at the lower boundary of Zone 2. *Picea* needles are abundant in the upper half of this zone. Otherwise, *Pinus* cf. *albicaulis/flexilis*, *Picea* and

Abies needles occur in roughly equal numbers with lesser numbers of *Pinus* cf. *contorta* throughout Zone 2.

LOH25 Zone 3, 122-168 cm. Pinus-Alnus-Picea assemblage zone.

LOH25 Zone 3 dates by extrapolation from ca. 7000 years BP to ca. 3000 years BP and contains Mazama tephra (6800 years BP). Zone 3 is characterized by a steady decrease in *Pinus* pollen percentages (79%-46%) accompanied by a steady increase in *Picea* pollen percentages (4%-17%). Haploxylon/diploxylon ratios indicate a shift towards predominately diploxylon pine pollen towards the top of this interval. *Abies* pollen percentages are relatively consistent ranging from 3%-8%, as are *Betula* (birch) pollen percentages which vary from 0.5%-2%. *Artemisia* and Gramineae pollen are present in low percentages throughout this zone as well as traces (< 1%) of Tubuliflorae (high spine) pollen. Total pollen concentrations in this zone are relatively low (about 4.0×10^5 grains/cm³) but vary considerably from 0.23×10^6 - 1.1×10^6 grains/cm³. The upper boundary of this zone is marked by a decrease in *Alnus* pollen percentages, accompanied by a drop in *Betula* pollen percentages to below 1%. This contact also marks the onset of the consistent presence of *Tsuga heterophylla* (western hemlock) pollen in low percentages. *Picea* and *Abies* needles are equally abundant in the lower half of this interval with both *Pinus* cf. *albicaulis/flexilis* and *Pinus* cf. *contorta* needles reduced in numbers from the previous zone. A sharp reduction in *Picea*, *Abies* and *Pinus* cf. *albicaulis/flexilis* needles occurs in Zone 3 at about 80 cm

depth in the core, along with the virtual disappearance of *Pinus* cf. *contorta* needles.

LOH25 Zone 4, 168-5 cm. *Pinus-Picea-Tsuga* assemblage zone.

Zone 4 postdates the extrapolated date of ca. 3000 years BP and contains Bridge River tephra (2350 years BP). *Pinus* pollen percentages increase from 57%-65% and *Picea* pollen percentages decrease from 22%-10% over Zone 4. The pine pollen in this zone is predominantly diploxylon type. *Abies* and *Betula* pollen percentages are relatively constant at about 5% and less than 1% respectively. *Alnus* pollen percentages decline from the preceding zone ranging from 7%-14%. *Tsuga heterophylla* pollen is present throughout this zone ranging from >1%-2%. The first appearance of *Oxyria* (mountain sorrel) pollen occurs in the upper half of this zone and persists at less than 1%. Total pollen concentrations, less variable than in the preceding zone, remain at about 4.0×10^5 grains/cm³ throughout Zone 4. *Picea* and *Abies* needles are present throughout this zone in relatively small numbers along with a few fragments of *Pinus* cf. *albicaulis/flexilis* needles.

Opabin Lake palaeobotanical data (Figure 5 and Figure 6)

OPB1 Zone 1, 110-98 cm. *Pinus-Artemisia* assemblage zone.

OPB1 Zone 1 predates ca. 8530 years BP. *Pinus* and *Artemisia* pollen are dominant in this zone varying from 29%-52% and 21%-32%, respectively.

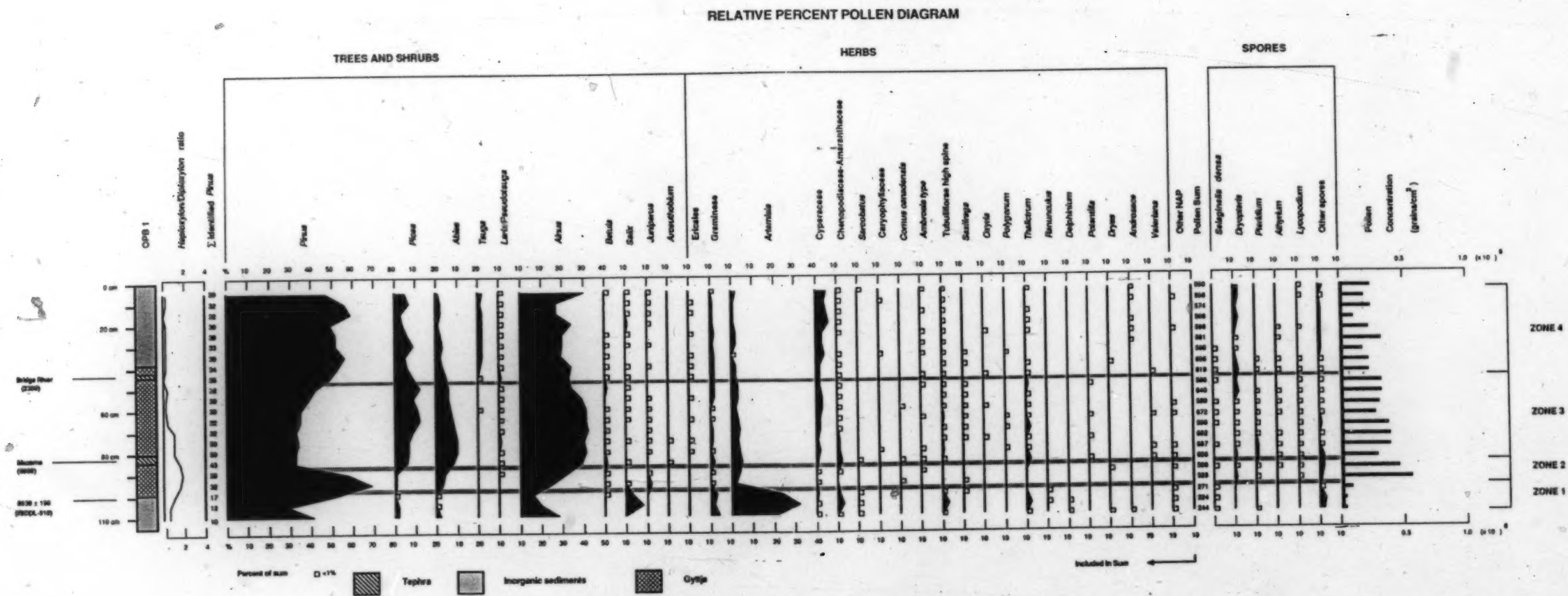


Figure 5-5. Pollen diagram from core OPB1, Opabin Lake.

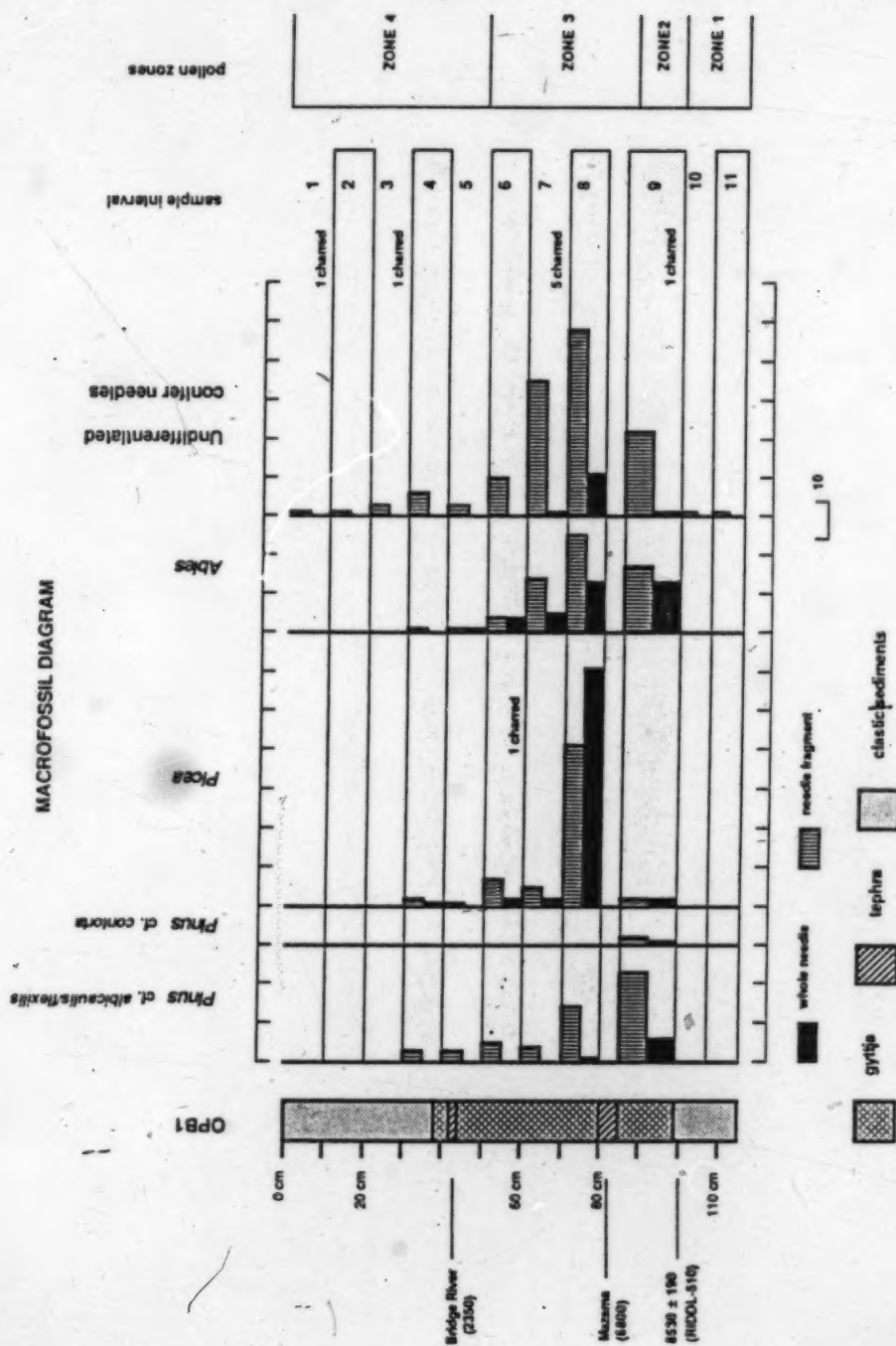


Figure 5-6. Macrofossil diagram from core OPB1, Opabin Lake.

Haploxylon/diploxylon ratios indicate that diploxylon pine pollen is dominant. *Salix* (2%-8%) and Gramineae (about 3%) pollen are also relatively common. Chenopodiaceae-Amaranthaceae, *Thalictrum* (meadow rue) and Tubuliflorae (high spine) pollen are present in low percentages in this zone ranging from less than 1% to 3%. *Picea* and *Abies* pollen also occur in low percentages (less than 2%). *Sarcobatus* (greasewood), *Delphinium* (larkspur), and *Ranunculus* (buttercup) pollen are present at less than 1%, the latter two being unique to this zone. Total pollen concentrations are very low in this zone varying from 2.0×10^4 - 7.0×10^4 grains/cm³. The upper boundary of this zone is defined by marked declines in *Artemisia*, *Salix* and Gramineae pollen percentages along with a sharp increase in *Pinus* pollen percentages. Sediments from this zone yielded no identifiable conifer needles.

OPB1 Zone 2, 98-86 cm. Pinus-Alnus-Abies assemblage zone.

OPB1 Zone 2 dates from 8530 years BP to an extrapolated date of ca. 7000 years BP. The primary feature of Zone 2 is dominated by a peak in *Pinus* pollen percentages (up to 69%) which is largely represented by haploxylon pine pollen. Accompanying the *Pinus* pollen peak are the highest *Juniperus* pollen percentages in this record (up to 2%) and sharp reductions in *Artemisia*, Gramineae, *Salix*, Chenopodiaceae-Amaranthaceae and Tublflorae (high-spine) pollen. *Abies* pollen increases over the zone to above 4% and *Alnus* pollen rises from 15%-23%. *Picea* pollen is present in low percentages

near 1%. *Dryopteris*, *Athyrium* and *Lycopodium* (club moss) spores make their first appearance in this zone. Zone 2 is further defined by the highest total pollen concentrations in the Opabin Lake record (4.0×10^5 - 5.0×10^5 grains/cm³). The upper boundary of OPB1 Zone 2 is defined by abrupt increases in *Picea* and *Abies* pollen percentages accompanied by a sharp decline in *Pinus* pollen percentages. *Pinus* cf. *albicaulis/flexilis* needles represent the majority of pine needles identified from this zone. *Pinus* cf. *contorta* needles are present in small numbers and are unique to this zone in this record. *Abies* needles are abundant in the zone whereas *Picea* needles only occur in small numbers.

OPB1 Zone 3, 86-48 cm. Alnus-Picea-Abies assemblage zone.

OPB1 Zone 3 dates by extrapolation from ca. 7000 years BP to ca. 3000 years BP and contains Mazama tephra (6800 years BP). Zone 3 is characterized by relatively low *Pinus* pollen percentages (33%-42%) accompanied by a steady shift over the zone towards diploxylon pine pollen dominance. *Picea* and *Abies* pollen are present throughout this interval at 6%-12% and 7%-10% respectively. *Cyperaceae* pollen increases slightly (1%-3%) whereas *Artemisia* pollen decreases over the zone from 6%-2%. *Thalictrum* pollen is present in low percentages (<2%). *Valeriana* (valerian), *Potentilla*, *Arceuthobium* and *Saxifraga* (saxifrage) pollen are minor constituents largely confined to this zone. *Dryopteris*, *Selaginella*, *Pteridium*, *Athyrium* and *Lycopodium* spores are also present throughout the zone. Zone 3 total pollen concentrations range from

3.0 X10⁵-4.0 X10⁵ grains/cm³. The upper boundary of this zone is marked by the first occurrence of *Tsuga heterophylla* in consistent but low percentages and is accompanied by declines in both *Picea* and *Abies* pollen percentages. *Picea* needles are abundant in the lower portion of this zone along with lesser numbers of *Abies* and *Pinus cf. albicaulis/flexilis* needles. *Abies* and *Pinus cf. albicaulis/flexilis* needles show a consistent decline in numbers towards the top of Zone 3.

OPB1 Zone 4, 48-5 cm. *Pinus-Cyperaceae-Tsuga* assemblage zone.

Bridge River tephra (2350 years BP) occurs in the lower part of Zone 4 which postdates the extrapolated age of ca. 3000 years BP. *Pinus* pollen percentages increase to about 50% in this interval but vary considerably from 47%-59%. Haploxylon/diploxylon ratios indicate that diploxylon pine pollen is dominant in Zone 4. *Alnus* pollen percentages are variable but generally lower than in the preceding zone (17%-30%). *Cyperaceae* pollen increases from 2%-6% over this zone whereas, *Picea* and *Abies* pollen decrease to 6% and 2% respectively. *Tsuga heterophylla* pollen is present throughout this zone in consistently low percentages (2%) as is *Androsace* (fairy candelabra) pollen (less than 1%). With the exception of *Dryopteris*, spores are not as well represented as in the preceding zone. Total pollen concentrations are the lowest in the core ranging from 0.8 X 10⁵-3.0 X 10⁵ grains/cm³. Only a few needles of *Picea*, *Abies* and *Pinus cf. albicaulis/flexilis* were identified in the

lower section of this zone. No identifiable needles were recovered from the upper half of OPB1 Zone 4.

PALAEOENVIRONMENTAL RECONSTRUCTION

The pollen and macrofossil records from Lake O'Hara and Opabin Lake reflect changes in Holocene vegetation and inferred climate at these adjacent subalpine and alpine sites. Differences in pollen frequencies between synchronous intervals of the LOH25 and OPB1 pollen records are presumed to be primarily related to the control of elevation on the distribution of past and present local vegetation in the vicinity of the lakes. However, the smaller surface area of Opabin Lake probably enhanced the contribution from local and extralocal vegetation relative to the Lake O'Hara pollen record (Jacobsen and Bradshaw 1981).

The use of pollen ratios to quantify fluctuations in Holocene timberline elevations involves calibrating the elevation of present timberline from modern pollen ratios obtained from a transect through the ecotone (Beaudoin 1986; Kearney 1981; Maher 1972). The method is site specific due to the interaction of local environmental factors that may influence vegetation independent of elevation (Beaudoin 1986). Modern pollen ratio data are not available from the upper Cataract Brook Valley. Consequently, pollen ratio data from the Opabin Lake core are used only in a qualitative sense, and in conjunction with the pollen and macrofossil records, to infer Holocene timberline fluctuations. Further, the

use of pollen ratios as a proxy record of timberline fluctuation can only be applied to sections of records that represent similar-to-present vegetation (Beaudoin 1986). *Abies/Pinus* and *Picea/Pinus* ratios derived from the pre-Mazama period of the Opabin Lake record are therefore not considered significant.

LOH25 Zone 1 (> ca. 10,100 years BP)

The very low total pollen concentrations and the presence of far travelled "long distance" pollen such as *Ephedra*, *Sarcobatus* and *Quercus* suggest that this lower interval of the Lake O'Hara core represents a period low local pollen productivity. A sparse herbaceous vegetation is inferred for the vicinity of Lake O'Hara at this time consisting of *Artemisia*, Gramineae and *Alnus*, with lesser abundance of *Shepherdia canadensis*, Tubuliflorae, and *Selaginella densa*. This assemblage of vegetation is interpreted to represent a colonizing shrub-herb community. *Artemisia* and Gramineae probably inhabited well drained areas in the vicinity of the lake. *Alnus* (*A. sinuata*) is a nitrogen fixer and readily invades recently exposed mineral materials left by retreating glaciers (Krajina *et al.* 1982). Modern occurrences of *Shepherdia canadensis*, also a nitrogen fixer, include open, unstable sites in the forest-tundra ecotone and recently deglaciated areas in Alaska, British Columbia and the Yukon (Birks 1976). The presence of *Alnus* and *S. canadensis*, along with *Artemisia* and Gramineae in Zone 1 of the Lake O'Hara record, support the interpretation that this shrub-herb vegetation represents a colonizing community.

Although the pollen record over this interval is dominated by diploxylon type *Pinus* pollen with lesser amounts of *Picea* and *Abies* pollen present, the relative paucity of fossil conifer needles suggests an extra-local origin for these arboreal pollen types. The tendency for pine pollen to be transported long distances and over-represented in pollen spectra has been noted by Faegri and Iversen (1975). Further, Lichti-Federovich and Ritchie (1968) demonstrated that the very low pollen production of modern tundra environments leads to the over-representation of arboreal pollen that has arrived via long distance transportation. The majority of *Pinus* pollen in this zone probably originated from *Pinus contorta* stands in the lower valleys. *Pinus contorta* was present in the region prior to ca. 11,200 years BP (MacDonald and Cwynar 1985).

Leonard (1986a, 1986b, 1987) demonstrated the existence of a strong relationship between clastic sediment input in lake basins and upvalley ice activity. High sedimentation rates occur during, and up to a century following deglaciation, in response to the exposure of unstable glacial deposits. The initial period of sparse shrub-herb vegetation in the vicinity of Lake O'Hara and its association with clastic sedimentation in the Lake O'Hara basin is interpreted as representing the influence of Late Wisconsinan deglaciation prior to 10,100 years BP (Figure 7a).

The inferred post-glacial pioneering herbaceous community at the Lake O'Hara site is similar in many aspects to a number of late-glacial tundra-like

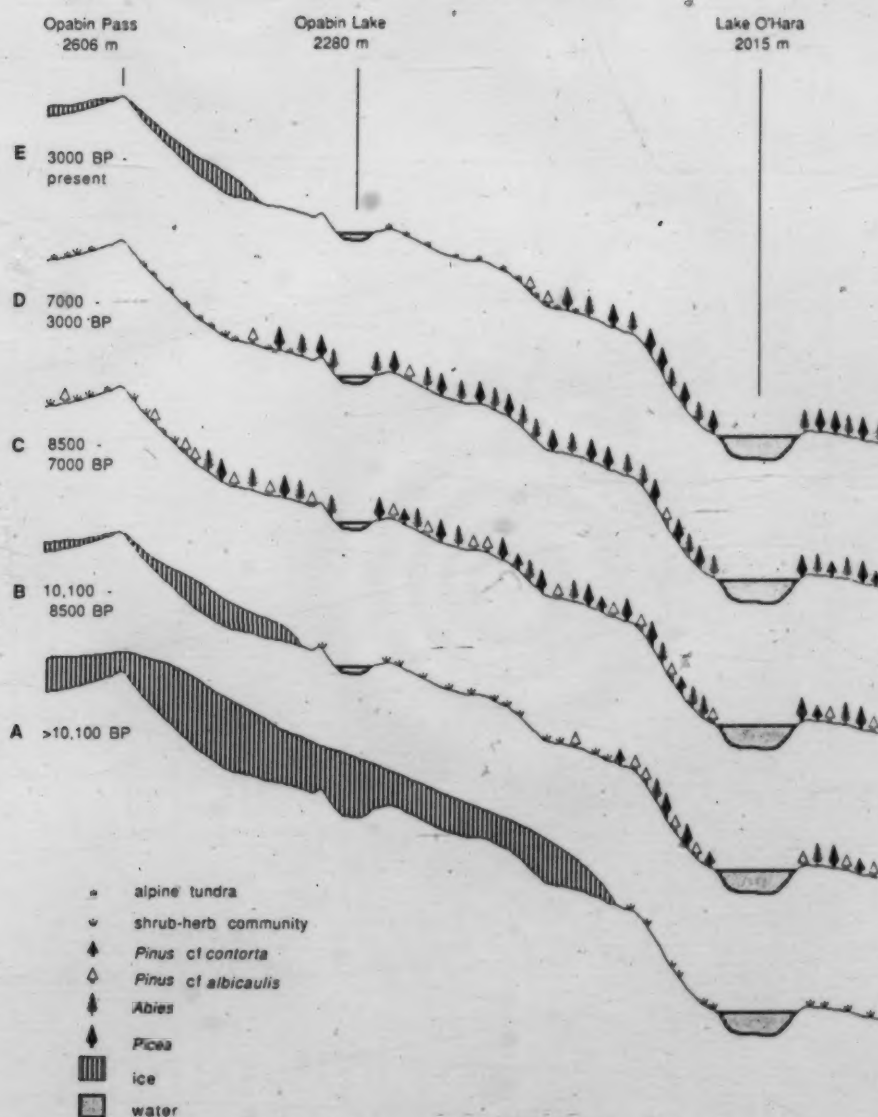


Figure 5-7. Schematic transect across the upper Cataract Brook Valley from Opabin Pass to Lake O'Hara showing dominant vegetation and ice distribution for the periods > 10,000 years BP (a), 10,000-8500 years BP (b), 8500-7000 years BP (c), 7000-3000 years BP (d), and 3000 years BP-present (e). Although abundant in the modern timberline ecotone, *Larix lyallii* is not represented in the reconstruction due to the inherent difficulty in distinguishing *Larix* pollen from *Pseudotsuga* pollen.

vegetation assemblages in the interior Pacific Northwest and northern Great Basin of the United States (Mehring 1985; Baker 1983) as well as several records from Alberta (Beaudoin 1984; MacDonald 1982; Mott and Jackson 1982; Fergusson 1978; Lichti-Federovich 1970; Schweger, personal communication, 1987). This early vegetation is typically dominated by *Artemisia* and Gramineae and often includes *Shepherdia canadensis*, *Juniperus*, *Populus* and *Selaginella densa* (Vance 1986; Mehring 1985). *Alnus* is an important component of the colonizing Lake O'Hara and Opabin Lake vegetation as well as Late Wisconsinan-Early Holocene shrub-herb vegetation in the Chugach Mountains of Alaska (Sirkin and Tuthill 1987). The Wilcox Pass record provided by Beaudoin (1984) is the only other record from an alpine setting in the central Canadian Rocky Mountains that documents a similar post-glacial tundra-like assemblage.

Post-glacial colonizing communities that include *Pinus contorta* as a major component have been reported by a number of workers from locations in northwestern North America (e.g., Mack *et al.* 1983; Kearney and Luckman 1983a; Mack *et al.* 1978a). The differences between these early pine dominated and shrub-herb records similar to the early Lake O'Hara and Opabin Lake records may, in part, reflect a Late Glacial mosaic of vegetation types consisting of sparsely forested communities juxtaposed with treeless vegetation. This coexistence of treeless and forested communities would have probably been enhanced in the Rocky Mountains by the influence of elevation and slope aspect on vegetation distributions. A similar coexistence of tundra-like and forested

vegetation has been proposed for the late-glacial of northwestern Montana by Mack *et al.* 1983).

Palaeoclimatic interpretations for this period are speculative primarily due to the lack of modern analogues for early tundra-like vegetation (Vance 1986) and the wide environmental range of many of the components. Further, colonizing vegetation responds to edaphic factors such as site availability and soil development as well as climatic conditions (Stork 1963). Relatively cool climatic conditions have often been associated with the presence of early treeless vegetation in records from northwestern North America (e.g., Fergusson and Hills 1985; Mack *et al.* 1978b, c) although some workers suggest these communities may have been seral in nature and have little climatic significance (Beaudoin 1984; Lichti-Federovich 1970). It appears, however, that the Late Glacial-Early Holocene may have been a relatively warm period (Vance 1986; Baker 1983; Matthewes and Heusser 1981; Verneker 1972) associated with relatively rapid ice retreat (Reasoner and Rutter in press). It is therefore unlikely that this early shrub-herb vegetation represents tundra that developed in response to regionally cold and harsh climatic conditions. It is difficult, however, to assess the degree to which the presence of alpine glaciers in the upper Cataract Brook Valley may have influenced the local microclimate.

LOH25 Zone 2, OPB1 Zones 1 and 2 (ca. 10,100-7000 years BP)

The abrupt increase in total pollen concentration, accompanied by the

appearance of abundant fossil conifer needles, and the shift to primarily organic sedimentation, indicate that the base of LOH25 Zone 2 represents the appearance of forest vegetation and stabilization of the landscape in the vicinity of Lake O'Hara at ca. 10,100 years BP. The Lake O'Hara pollen and macrofossil records suggest this pioneering forest comprised *Pinus* cf. *albicaulis/flexilis* and *Abies* with lesser *Picea* and *Pinus* cf. *contorta*. The higher haploxylon/diploxylon ratios also indicate the importance of haploxylon pine in the local forest. *Alnus* probably inhabited avalanche paths adjacent to the lake where it is common in the modern vegetation. The presence of a variety of spore types suggests the existence of several species of Polypodiaceae (ferns) as well as *Lycopodium* and *Selaginella densa* as components in the understory of the conifer forest.

During this period of forest colonization in the vicinity of Lake O'Hara, Opabin Lake was receiving predominantly clastic sediments, and the local environment supported a treeless shrub-herb vegetation dominated by *Artemisia*, *Salix* and *Alnus* (OPB 1 Zone 1). With the exception of the presence of abundant *Salix* near the Opabin site, this vegetation is similar to the community proposed for the pre-10,100 years BP period in the vicinity of Lake O'Hara (Figure 7b). The lack of fossil conifer needles in the pre-8530 years BP section of the Opabin Lake record suggests that the coniferous pollen taxa in OPB1 Zone 1 are not of local origin. The combination of clastic sediment input and a sparse local shrub-herb vegetation at the Opabin site indicates the Upper Cataract

Brook Valley was influenced by glacial activity during the period 10,100-8500 years BP. It remains uncertain whether this combination of clastic sediment input and local herbaceous vegetation present in Zone 1 of the Opabin record represents the influence of the poorly dated Crowfoot Advance (Luckman and Osborn 1979) or the latter phases of Late Wisconsinan deglaciation above Opabin Lake. In either case, the records from the upper Cataract Brook Valley suggest the presence of this early shrub-herb assemblage in subalpine/alpine records has little chronostratigraphic significance. Sirkin and Tuthill (1987) also note the time transgressive nature of post-glacial shrub-herb communities in the Chugach Mountains of Alaska.

The sharp increase in total pollen concentration, the first appearance of abundant fossil conifer needles, and the shift from clastic to primarily organic sedimentation indicate that the base of OPB1 Zone 2 (ca. 8350 years BP) represents the stabilization of the landscape by forest vegetation in the vicinity of Opabin Lake (Figure 7c). The presence of a local forest at Opabin Lake at this time indicates a shift of the timberline ecotone to at least 90 m above modern timberline elevations. The Opabin Lake pollen and macrofossil records indicate the local forest was composed of *Pinus* cf. *albicaulis/flexilis* and *Abies* with lesser numbers of *Picea* and *Pinus* cf. *contorta*. Further, haploxylon/diploxyylon pollen ratios for this zone indicate that *Pinus* was largely represented by haploxylon pine. *Alnus* was likely abundant on the steep avalanche paths near the Opabin site. Also present as elements of the understory flora were

Polypodiaceae including *Dryopteris* and *Pteridium* as well as *Lycopodium*. In the Alberta Rocky Mountains, *Juniperus* presently inhabits exposed, well drained sites (Moss 1983). The presence of *Juniperus* suggests these habitats existed near Opabin Lake during the early stages of this period.

Although the composition of the timberline forest at this time differed somewhat from the modern timberline ecotone, higher than present timberlines indicate the period 8500-7000 years BP was characterized by relatively warm climatic conditions. The modern relationship between timberline position and the July 10° C isotherm (Tranquillini 1979) suggests that the elevated timberlines probably reflected warmer summer conditions. These relatively warm climatic conditions associated with elevated timberlines, and the abrupt shift to primarily organic sedimentation in the Opabin Lake basin, indicate that ice extent upvalley from Opabin Lake was significantly reduced.

Several alpine/subalpine records from the Canadian Rocky Mountains document a pre-Mazama interval with forest compositions represented by *Pinus albicaulis*, *Picea* and *Abies* (Luckman and Kearney 1986; Beaudoin 1984; Kearney and Luckman 1983a; and Kearney and Luckman 1981). Kearney and Luckman (1983a, 1981) interpreted this early forest association as representing a change to cooler conditions in the Tonquin Pass area based on the modern abundance of *Pinus albicaulis* in the timberline ecotone. Kearney and Luckman (1983a) consider this interpretation of climatic deterioration provisional due to the lack of modern pollen spectra in the area that resemble pollen in the pre-Mazama

section of the Tonquin Pass record. In contrast, relatively warm Early Holocene conditions have been proposed for locations in northwestern North America by many workers (Luckman and Kearney 1986; Vance 1986; Barnosky 1984, 1985; Baker 1983; Matthewes and Heusser 1981; Alley 1976). Beaudoin (1984) suggests that the early Holocene abundance of *Pinus albicaulis* at Wilcox Pass may not reflect cooler climatic conditions but, alternatively, is more likely related to the absence of significant competition from other tree species. This argument is supported by the association of an Early Holocene *Pinus albicaulis/flexilis* - *Abies* forest with a period of relative warmth and elevated timberlines in the upper Cataract Brook Valley.

LOH25 Zone 3, OPB1 Zone 3 (ca. 7000-3000 years BP)

The establishment of a *Picea* and *Abies* forest with reduced abundance of *Pinus* in the upper Cataract Brook Valley during the period ca. 7000-3000 years BP is inferred from Lake O'Hara and Opabin Lake pollen and macrofossil records (Figure 7d). Haploxylon/diploxylon ratios from both pollen records indicate that a shift towards dominance by diploxylon-type pine occurred over this interval. In contrast, the macrofossil records indicate the disappearance of *Pinus* cf. *contorta* from the vicinity of both lakes, although *Pinus* cf. *albicaulis/flexilis* persisted in reduced numbers. Presumably, the majority of the diploxylon type pine pollen originated from lower elevation *Pinus contorta* stands.

The relatively high percentages of *Alnus* pollen in both records suggests

its continued abundance on nearby avalanche paths or in open areas fringing the lakes. The increased abundance of *Betula* pollen accompanied by the occurrence of *Valeriana* and *Cornus canadensis* pollen in the Lake O'Hara record indicate the presence of these taxa in the understory vegetation. *B. glandulosa* (dwarf birch) is common to modern subalpine and alpine environments in Western Canada (Moss 1983) and is the likely source of *Betula* pollen during this interval. Polypodiaceae as well as *Lycopodium* spores remained consistent components of the understory communities at both sites.

The presence of abundant fossil conifer needles in the Opabin Lake record indicate that elevated timberlines existed in the upper Cataract Valley during the period ca. 7000-3000 years BP. Consequently, relatively warm climatic conditions are inferred for this period. The record however, shows a gradual decline in fossil needle abundance over this interval, with the exception of *Picea* which shows a sharp peak from 80-70 cm. This decline may be related to more open forest cover in the vicinity of Opabin Lake and/or declining timberlines elevations upvalley. Further, this part of the Opabin record shows generally consistent declines in both *Picea/Pinus* and *Abies/Pinus* ratios (Figure 8) which suggests that timberlines declined gradually during this period, but not below the elevation of Opabin Lake.

The Lake O'Hara macrofossil record shows a marked decline in all needle types at ca. 5000 years BP. The magnitude and timing of this decline in

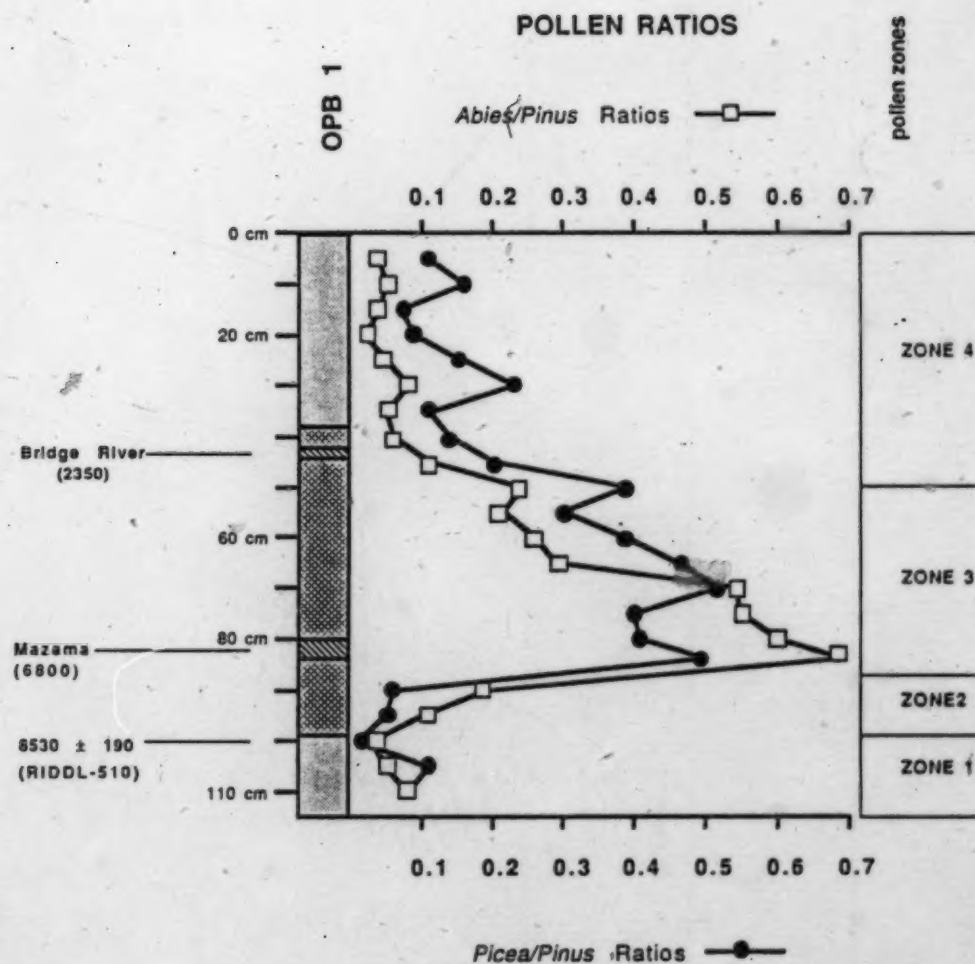


Figure 5-8. Pollen ratio (*Abies/Pinus* and *Picea/Pinus*) from core OPB1, Opabin Lake. The ratios have been corrected for the amount of haploxylon pine pollen that may have originated from whitebark pine in the timberline ecotone.

needle concentration in the Lake O'Hara record is puzzling in that it is synchronous with a period of elevated timberlines above the higher altitude Opabin Lake site. Also, a corresponding abrupt decline in total pollen concentrations, or significant change in pollen spectra, is not evident in either the Lake O'Hara or Opabin Lake records. The needle concentration decline in the Lake O'Hara record may be related to climatic conditions associated with reduced local tree density and/or slightly lower timberline elevations at ca. 5000 years BP in the upper Cataract Brook Valley. Alternatively, this decrease in fossil needle concentration may be, at least in part, related to increased sedimentation rates in the Lake O'Hara basin during this interval (Reasoner and Rutter in press).

Evidence for a relatively warm mid-Holocene period characterized by elevated timberlines in the Central Rocky Mountains has been reported by Beaudoin (1986, 1984), Luckman and Kearney (1986) and Kearney and Luckman (1983a, b). Pollen ratios from Wilcox Pass (Beaudoin 1986), and the Opabin Lake pollen and macrofossil records, imply that timberlines remained higher than present in the region throughout the period ca. 7000-3000 years BP. The gradual mid-Holocene decline in elevation of the timberline ecotone above the Opabin Lake site, and the possible reduction in forest density in the vicinity of Lake O'Hara at ca. 5000 years BP, may be related to the decline of the timberline ecotone at ca. 5200-4500 years BP in the Watchtower Basin in Jasper National Park (Luckman and Kearney 1986; Kearney and Luckman 1983b). Although the Watchtower site is situated 138 m lower than Opabin Lake, the

timberline ecotone may have migrated to elevations below the Watchtower basin at ca. 5200 years BP, and remained above Opabin Lake, as a result of latitudinal variations in the altitude of timberlines.

LOH25 Zone 4, OPB1 Zone 4 (ca. 3000 years BP-present)

Stable forest compositions similar to modern *Picea engelmannii*-*Abies lasiocarpa* subalpine forests were probably established in the vicinity of Lake O'Hara by ca. 3000 years BP (Figure 7e). Although diploxylon-type pine pollen dominates the pollen record, *Pinus* cf. *contorta* needles are absent from the macrofossil record suggesting an exogenous origin for this pollen. *Alnus* was abundant throughout this interval, probably on avalanche paths or open areas fringing the lake. During this period, understory components such as *Oxyria*, *Salix*, *Lycopodium* and Polypodiaceae approach modern abundances in the valley. The presence of *Betula* pollen in consistently lower percentages than in the preceding zone, accompanied by the disappearance of *Cornus canadensis* from the pollen record suggests the reduced numbers of these taxa near the site. Relatively low numbers of fossil needles in the Lake O'Hara macrofossil record occur at ca. 1000 years BP, probably reflecting lowered timberline elevations upvalley and/or reduced tree density in the forest surrounding the site. In general, the pollen and macrofossil records indicate that only minor changes occurred in the vegetation surrounding Lake O'Hara occurred in this period.

In contrast to the Lake O'Hara records, the Opabin Lake records show

considerable variation during the Late Holocene. The Opabin Lake pollen record indicates declining *Abies* and *Picea* along with increasing Cyperaceae and *Pinus* pollen percentages for this period. The Opabin Lake macrofossil record indicates the complete disappearance of *Pinus* cf. *albicaulis/flexilis*, *Picea* and *Abies* from the vicinity of Opabin Lake by ca. 1500 years BP. Consequently, much of the arboreal pollen in OPB1 Zone 4, particularly that representing the last ca. 1500 years BP, probably originated from forests situated at lower elevations. The OPB1 pollen record, in conjunction with dominantly clastic sedimentation (Figure 2), indicates a return to sparse local vegetation dominated by Cyperaceae, with *Androsace* and Gramineae present. A number of components of the modern alpine vegetation of the area are poorly represented or absent from Zone 4 of the Opabin Lake record. Modern pollen studies of alpine tundra at Sunwapta Pass (Beaudoin 1987) indicate that several common components of the alpine flora such as *Dryas*, *Potentilla*, and *Salix* may be under-represented in the pollen spectra with respect to Cyperaceae and exogenous taxa.

The shift to alpine tundra vegetation in the vicinity of Opabin Lake records the downslope passage of the timberline ecotone to elevations below Opabin Lake between ca. 1500-1000 years BP (Figure 7e). Pollen ratios from the Opabin record also indicate minimum timberline elevations at ca. 1000 years BP (Figure 8) which is very similar to the timing of minimum timberline elevations derived from the Wilcox Pass record (Beaudoin 1984, 1986). This drop in

timberline elevation reflects deteriorating climatic conditions associated with the Neoglacial period. The predominantly clastic sediments representing the post-Bridge River section of the Opabin Lake core presumably reflect increased sediment input associated with advancing Late Neoglacial ice upvalley from the lake (Leonard 1986a).

Tsuga heterophylla is not a component of the modern subalpine forests in the upper Cataract Brook drainage (Coen and Kuchar, 1982) although its pollen consistently occurs in low percentages from ca. 3000 years BP to present in both the Lake O'Hara and the Opabin Lake pollen records. The occurrence of *T. heterophylla* pollen in the Late Holocene alpine part of the Opabin Lake record confirms its long distance origin, probably from lower elevation forests situated to the west of the study area (Rowe 1972). The Late Holocene presence of *T. heterophylla* pollen has been documented in other alpine records in the region (Beaudoin 1984; Kearney and Luckman 1986). Due to its narrow environmental range (Mack *et al.* 1983; Moss 1980; Rowe 1972), it is unlikely that *T. heterophylla* was at any time a component of the subalpine forest in the upper Cataract Brook Valley. Its presence in these pollen records probably reflects a regional eastward migration of the species (Baker 1983) during the Late Holocene. This regional expansion of *T. heterophylla*, and perhaps other mesophytic forest components, may be related to increased regional precipitation over the southern cordillera during the last 3000 years (Vance 1986; Beaudoin 1984; Mack 1978a, b).

A Late Holocene shift to predominantly alpine vegetation has been recognised from high elevation records in the Canadian Rockies (Beaudoin 1984; Luckman and Kearney 1986) as well as alpine sites in the American Rocky Mountains (Carrara *et al.* 1984; Andrews *et al.* 1975) and has largely been attributed to reduced timberline elevations associated with Late Holocene climatic deterioration and renewed glacial activity (Luckman 1986). The timing of initial Late Holocene climatic deterioration in Western Canada has not been conclusively established (Beaudoin 1986). Estimates range from ca. 5200-4500 years BP (Luckman and Kearney 1986; Kearney and Luckman 1981, 1983b) to ca. 2750 years BP (Beaudoin 1984, 1986). Pollen ratio data from Wilcox Pass indicate minimum timberline elevations occurred at ca. 1000 years BP (Beaudoin 1986) which corresponds to the minimum elevation derived from the Opabin record (Figure 8). However, Kearney and Luckman (1986) report minimum timberline elevations in the Maligne Range occurred during the last 500 years BP based on pollen ratios and macrofossil data. Minor differences between the timing of Holocene events are probably reflect the variable influence of environmental change on vegetation at different elevations, climates and locations (Beaudoin 1984).

During the Late Holocene period of climatic deterioration and renewed glacial activity in the vicinity of Opabin Lake, the Lake O'Hara record registered only minor fluctuations. Similarly, the Opabin Lake record registered dramatic fluctuations prior to ca. 7000 years BP whereas the Lake O'Hara shows little

change over the period 10,100-7000 years BP. The discrepancies between the sedimentary and palaeobotanical records from the two lakes during the Late Holocene and the period 10,100-8500 years BP suggest that climatic fluctuations responsible for events on the scale of the Little Ice Age are best preserved in the more sensitive alpine lacustrine records.

CONCLUSIONS

The Lake O'Hara and the Opabin Lake records contain evidence for Holocene vegetational change at subalpine and alpine sites respectively. A colonizing assemblage of shrub-herb vegetation dominated by *Artemisia*, *Alnus* and Gramineae was present at the Lake O'Hara site prior to 10,100 years BP and at the Opabin Lake before 8530 years BP. The pioneering forest at both sites was composed *Pinus* cf. *albicaulis/flexilis* and *Abies* with less abundant *Picea* and *Pinus* cf. *contorta*. By 8350 years BP, the timberline ecotone had migrated to elevations above the Opabin Lake site, in response to relatively warm climatic conditions during the Early Holocene. Timberline declined gradually throughout the period 7000-3000 years BP, although it remained at elevations above Opabin Lake. The absence of glacial sediments in the 7000-3000 year BP section of the Opabin record reflects the restricted upvalley glacial activity during the period and is consistent with the early-mid Holocene period of increased warmth and associated elevated timberlines inferred from other records in the region (Vance 1986; Beaudoin 1986). The period 3000 years BP to present was marked by

deteriorating climatic conditions associated with renewed glacial activity in the Opabin cirque. Glacigenic sediments are evident in the Opabin record in the post-Bridge River (ca. 2350 years BP) interval and the timberline ecotone dropped to elevations below Opabin Lake at ca. 1500 years BP.

Abrupt changes in the Opabin record prior to 7000 years BP and following 3000 years BP reflect the migration of timberline and the influence of glacial ice in the vicinity of Opabin Lake. Relatively minor changes are evident during the same intervals of the Lake O'Hara record which suggests that glacial events, similar in magnitude to the Little Ice Age, are not well represented in records from subalpine sites.

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CHAPTER 6

SUMMARY

This study has documented aspects of the Late Quaternary alpine and subalpine lacustrine records from the upper Cataract Brook Valley. The objectives of this investigation were: (1) to develop a practical coring method for remote areas; (2) to establish the geochronology of the cores and assess its significance in terms of deglaciation; (3) to evaluate the the reliability of sedimentation rate data and bulk sediment amino acid ratios, and (4) to reconstruct Late Quaternary palaeoenvironmental change in the area.

(1) A lightweight, percussion coring system was developed for winter use in remote areas. Two ropes are employed in the operation of the system which is conducted from the surface of the ice pack. The main line is used to raise and lower the core barrel assembly and a secondary line operates the driver. The driver is guided to the core barrel assembly by the main line. The mechanical advantage required for core removal is obtained from a simple pulley system anchored to the surface of the ice pack. The equipment can be transported and operated by one person in the field and is theoretically unrestricted by water depth. The equipment was successfully tested under winter conditions and recovered 7.6 cm diameter core samples up to 257 cm in length.

(2) Core samples recovered from Mary Lake, Lake O'Hara, and Opabin Lake

show a consistent stratigraphy comprising gyttja and underlying inorganic clastic sediments. The gyttja contains Bridge River (2350 years BP) and Mazama (6800 years BP) tephras and is separated from the lower clastic sediments by a sharp, conformable contact. Identification of the tephras was initially based on distinctive colour, texture, phenocryst assemblages, and glass shard habits and was confirmed by electron microprobe analysis (EMPA) of the constituent glass shards. The microprobe technique employed backscattered (BSE) and secondary electron (SE) imagery and both energy dispersive and wavelength dispersive analyses. Analyses of glass shard composition by grain discrete EMPA are potentially subject to contamination from glass-encased microlites. Therefore, microprobe analyses of shards, generated without the aid of high-resolution transmitted-light optics and (or) BSE or SE imagery, may yield anomalous compositions. This is particularly true for analyses of tephras that have abundant gas vesicles and microlites.

Radiocarbon dates obtained from conifer needles, extracted from directly above the contact, indicate that deglaciation had proceeded upvalley from the O'Hara basin prior to ca. 10,100 years BP. Preliminary palaeobotanical and macrofossil data suggest that a *Pinus* - *Abies* forest with lesser *Picea* was established in the vicinity of Lake O'Hara by this time. Consequently, the minimum age of moraine systems situated downvalley from Lake O'Hara is Late Wisconsinan. These basal radiocarbon dates of ca. 10,100 years BP from the

Lake O'Hara cores impart considerable constraint on the timing of the deglaciation of the Bow Valley. Assuming the estimates of other workers for the timing of deglaciation in the lower Bow Valley are reasonable, it appears that ice may have receded from the lower valley to well within high cirques near the Continental Divide during a period of ca. 1000 to 3000 years.

(3) Mean annual sedimentation rates were derived from sediment thickness data from 14 Lake O'Hara and 2 Opabin Lake cores. Averaged total sedimentation rate values from the Lake O'Hara cores are 0.13 mm/yr (post - Bridge River), 0.13 mm/yr (Mazama - Bridge River) and 0.05 mm/yr (10,100 years BP - Mazama). Averaged total sedimentation rate values from the Opabin Lake cores are 0.19 mm/yr (post - Bridge River), 0.07 mm/yr (Mazama - Bridge River) and 0.06 mm/yr (8530 years BP - Mazama). Higher total sedimentation rates in post - Bridge River Opabin Lake sediments are presumably related to climatic conditions associated with more extensive upvalley ice during the last 2300 years. Highly variable total sedimentation rate data obtained from Lake O'Hara cores suggest that the focus of sedimentation in the O'Hara basin has shifted considerably during the Holocene. Consequently, the use of total sedimentation rate data as a proxy record of upvalley glacial activity is inappropriate in the Lake O'Hara setting where the inflowing glacial stream systems are interrupted by upvalley lake basins.

Aspartic acid D/L ratios were derived from bulk gyttja samples of known

age from 7 Lake O'Hara and 1 Opabin Lake cores. In all but two cases, aspartic acid D/L ratios increase consistently with respect to sediment age. The increasing downcore trends in the aspartic acid D/L ratios suggest the possibility of using amino acid data from bulk gyttja samples as a check for reworking in cases where chronostratigraphic markers are absent.

(4) The Lake O'Hara and the Opabin Lake records contain evidence for Holocene vegetational change at subalpine and alpine sites respectively. A post-glacial assemblage of shrub-herb vegetation dominated by *Artemisia*, *Alnus* and Gramineae was present at the Lake O'Hara site prior to 10,100 years BP and at the Opabin Lake before 8530 years BP. It remains uncertain whether the combination of clastic sediment input with local herbaceous vegetation prior to ca. 8530 years BP in the Opabin record represents a return to cooler climatic conditions associated with the poorly dated Crowfoot Advance or the latter phases of Late Wisconsinan deglaciation at Opabin Lake.

The pioneering forest at both sites was composed *Pinus cf. albicaulis/flexilis* and *Abies* with less abundant *Picea* and *Pinus cf. contorta*. By 8530 years BP, the timberline ecotone had migrated to elevations above the Opabin Lake site, in response to warm climatic conditions during the Early Holocene. Timberline declined gradually throughout the period 7000-3000 years BP, although it remained at elevations above Opabin Lake. The absence of glacial sediments in the 7000-3000 year BP section of the Opabin record

reflects the restricted upvalley glacial activity during the period and is consistent with the early-mid Holocene period of increased warmth and associated elevated timberlines inferred from other records in the region .

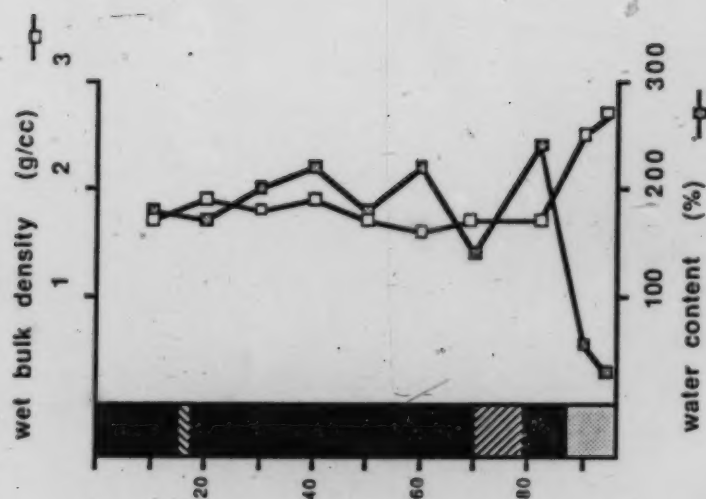
The period 3000 years BP to present was marked by deteriorating climatic conditions associated with renewed glacial activity in the Opabin cirque. Glacigenic sediments are evident in the Opabin record in the post-Bridge River (ca. 2350 years BP) interval, and the timberline ecotone dropped to elevations below Opabin Lake at ca. 1500 years BP.

Abrupt changes in the Opabin record prior to 8500 years BP and following 3000 years BP reflect the migration of timberline and the influence of glacial ice in the vicinity of Opabin Lake. Relatively minor changes are evident in the same intervals of the Lake O'Hara record which suggests that glacial events, similar in magnitude to the Little Ice Age, are not well represented in records from subalpine sites.

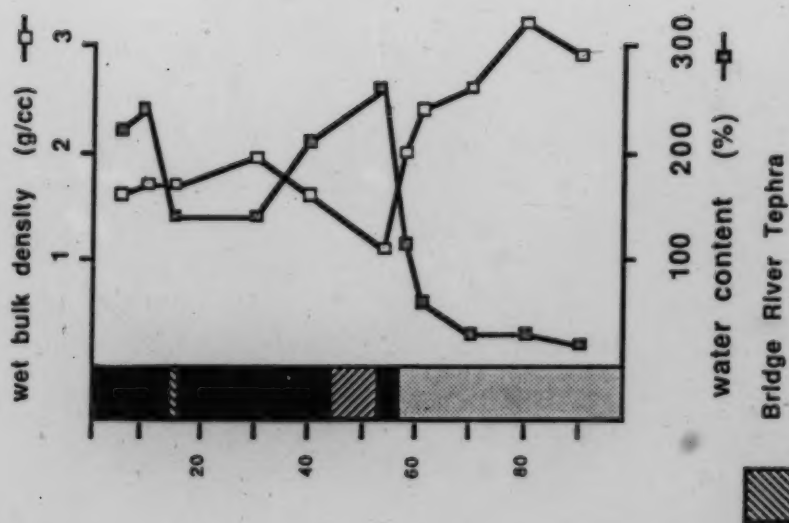
APPENDIX 1

GEOTECHNICAL DATA

LOH 14



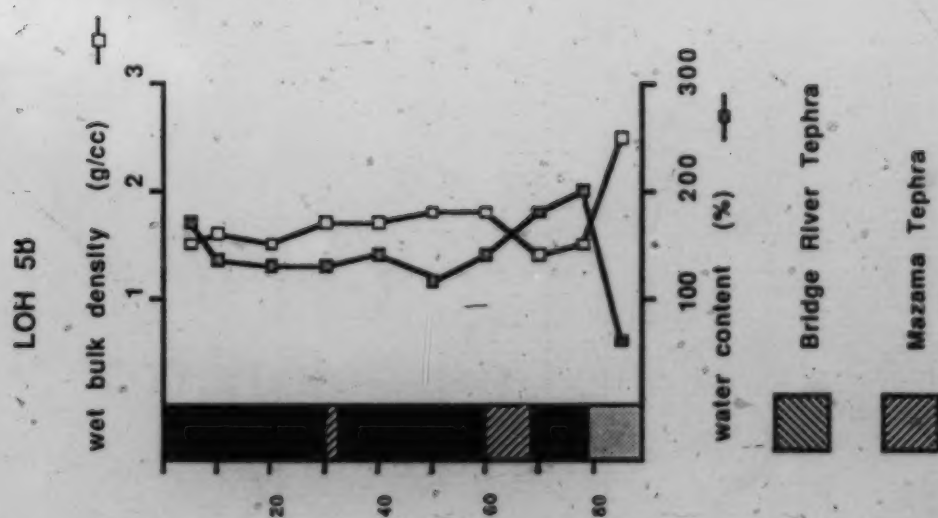
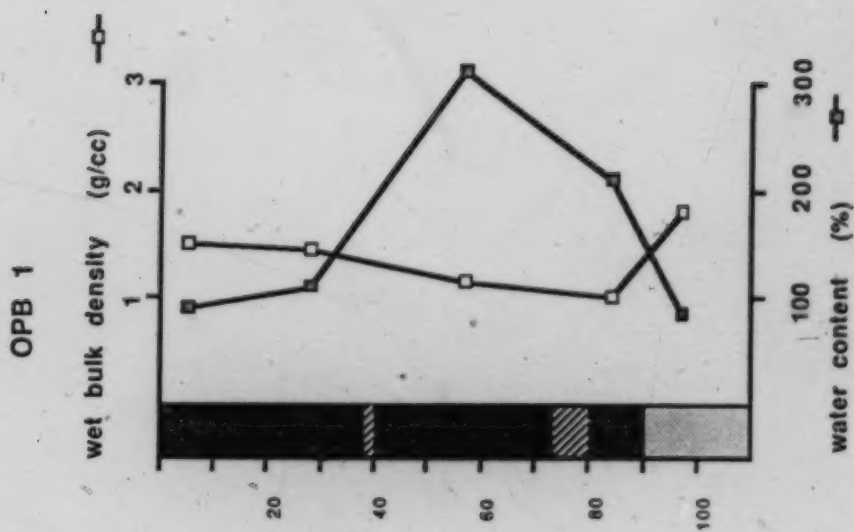
LOH 15



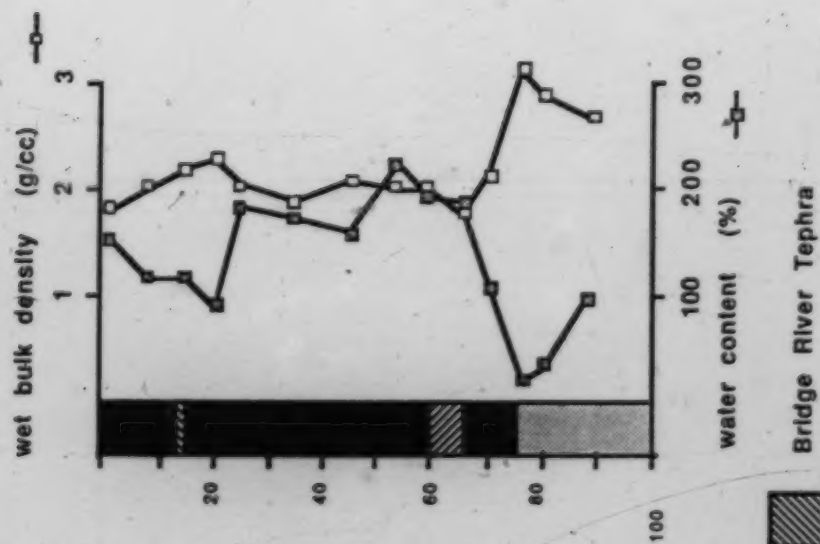
Bridge River Tephra



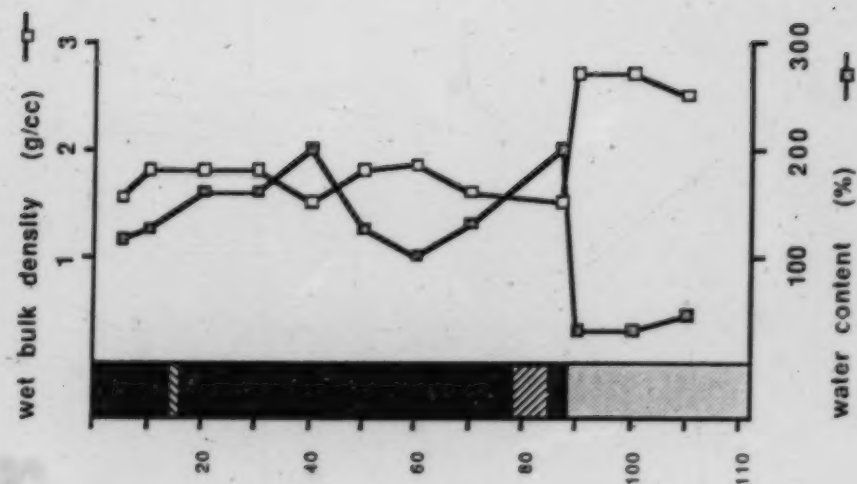
Mazama Tephra



LOH 23



LOH 6b



APPENDIX 2

POLLEN DATA

FILE: O'HARA

19 PRINCIPAL OF 22 IDENTIFIED TAXA

SAMPLE: 30 - DEPTH: 155CM - CONTAMINANT: 24980 #

COMMENT: CORE BASE. INORGANIC SEDIMENT

FAMILY	PRINCIPAL TAXA	COUNT	FREQ.	95%	CI	CONC.	INF.
PINACEAE	PINUS HAPL	1	.38%	0	2	50	.5
PINACEAE	PINUS DIPL	10	3.8%	2	6	496	.5
PINACEAE	PINUS	194	73.76%	68	78	9615	.5
PINACEAE	LARIX/PSEU	1	.38%	0	2	50	.5
PINACEAE	PICEA	6	2.28%	1	4	297	.5
RANUNCULACEAE	THALICTRUM	2	.76%	0	2	99	.5
BETULACEAE	ALNUS	7	2.66%	1	5	347	.5
BETULACEAE	BETULA	1	.38%	0	2	50	.5
FAGACEAE	QUERCUS	4	1.52%	0	3	198	.5
GRAMINEAE	GRAMINEAE	9	3.42%	1	6	446	.5
CYPERACEAE	CYPERACEAE	3	1.14%	0	3	149	.5
COMPOSITAE	TUBIFL. H.S.	2	.76%	0	2	99	.5
COMPOSITAE	ARTEMISIA	11	4.18%	2	7	545	.5
CHENO-AM	CHENO-AM	1	.38%	0	2	50	.5
CHENO-AM	SARCOBATUS	3	1.14%	0	3	149	.5
EPHEDRACEAE	EPHEDRA	3	1.14%	0	3	149	.5
ELAEAGNACEAE	SHEPHERDIA CAN	1	.38%	0	2	50	.5
BALSAMINACEAE	IMPATIENS	2	.76%	0	2	99	.5
LEGUMINOSAE	ASTRAGALUS	2	.76%	0	2	99	.5
SUM		263#					

CONTAM. COUNT: 504 #

CONCENTRATION: 13035#/CM3

FAMILY	EXCLUDED TAXA	COUNT	FREQ.	95%	CI
SELAGINELLACEAE	SELAGINELLA	4	1.52%	0	3
MISCEL	INDET BIS	92	34.98%	29	40
MISCEL	UNKNOWN	5	1.9%	0	4

FILE: O'HARA

19 PRINCIPAL OF 23 IDENTIFIED TAXA

SAMPLE: 29 - DEPTH: 150CM - DEPOSITION RATE: 0 CM/YR - CONTAMINANT: 24980 #

COMMENT: NONE

FAMILY	PRINCIPAL TAXA	COUNT	FREQ.	95%	CI	CONC.	INF.
PINACEAE	PINUS HAPL	8	1.25%	0	2	270	.5
PINACEAE	PINUS DIPL	17	2.66%	1	4	575	.5
PINACEAE	PINUS	562	88.08%	85	90	18997	.5
PINACEAE	PICEA	8	1.25%	0	2	270	.5
PINACEAE	ABIES	6	.94%	0	2	203	.5
BETULACEAE	ALNUS	4	.62%	0	1	135	.5
BETULACEAE	BETULA	1	.15%	0	0	34	.5
FAGACEAE	QUERCUS	4	.62%	0	1	135	.5
GRAMINEAE	GRAMINEAE	3	.47%	0	1	101	.5
CYPERACEAE	CYPERACEAE	4	.62%	0	1	135	.5
COMPOSITAE	TUBULIFL H.S.	1	.15%	0	0	34	.5
COMPOSITAE	ARTEMISIA	9	1.41%	0	2	304	.5
CHENO-AM	CHENO-AM	1	.15%	0	0	34	.5
CHENO-AM	SARCOBATUS	4	.62%	0	1	135	.5
EPHEDRACEAE	EPHEDRA	1	.15%	0	0	34	.5
ELAEAGNACEAE	SHEPHERDIA CAN	1	.15%	0	0	34	.5
MYRICACEAE	MYRICA	1	.15%	0	0	34	.5
BALSAMINACEAE	IMPATIENS	1	.15%	0	0	34	.5
LEGUMINOSAE	ASTRAGALUS	2	.31%	0	1	68	.5

SUM

638#

CONTAM. COUNT: 739 #

CONCENTRATION: 21566#/CM3

INFLUX: 0 #/CM2/YR

FAMILY	EXCLUDED TAXA	COUNT	FREQ.	95%	CI
SELAGINELLACEAE	SELAGINELLA	6	.94%	0	2
MISCEL	UNKNOWN	3	.47%	0	1
MISCEL	INDET BIS	78	12.22%	9	14
MISCEL	TRILETE SPO	2	.31%	0	1

FILE: O'HARA

18 PRINCIPAL OF 24 IDENTIFIED TAXA

SAMPLE: 28 - DEPTH: 145CM - DEPOSITION RATE: 0 CM/YR - CONTAMINANT: 24980 #

COMMENT: INORGANIC SEDIMENT. BELOW CONTACT WITH OVERLYING GYTTJA

FAMILY	PRINCIPAL TAXA	COUNT	FREQ.	95%	CI	CONC.	INF.
PINACEAE	PINUS HAPL	8	1.38%	0	2	520	.5
PINACEAE	PINUS DIPL	16	2.77%	1	4	1041	.5
PINACEAE	PINUS	437	75.86%	72	79	28428	.5
PINACEAE	PICEA	10	1.73%	0	3	651	.5
PINACEAE	ABIES	12	2.08%	1	3	781	.5
RANUNCULACEAE	THALICTRUM	1	.17%	0	0	65	.5
SAXIFRAGACEAE	SAXIFRAGACEAE	1	.17%	0	0	65	.5
BETULACEAE	ALNUS	23	3.99%	2	5	1496	.5
SALICACEAE	SALIX	5	.86%	0	2	325	.5
FAGACEAE	QUERCUS	2	.34%	0	1	130	.5
GRAMINEAE	GRAMINEAE	11	1.9%	1	3	716	.5
CYPERACEAE	CYPERACEAE	4	.69%	0	1	260	.5
COMPOSITAE	ARTEMISIA	38	6.59%	4	8	2472	.5
COMPOSITAE	TUBULIFL H.S.	2	.34%	0	1	130	.5
COMPOSITAE	LIGULIFLORAE	1	.17%	0	0	65	.5
CHENO-AM	CHENO-AM	2	.34%	0	1	130	.5
CHENO-AM	SARCOBATUS	2	.34%	0	1	130	.5
ELAEANACEAE	SHEPHERDIA CAN	1	.17%	0	0	65	.5

SUM 576#

CONTAM. COUNT: 384 #

CONCENTRATION: 37470#/CM3

INFLUX: 0 #/CM2/YR

FAMILY	EXCLUDED TAXA	COUNT	FREQ.	95%	CI
SELAGINELLACEAE	SELAGINELLA	3	.52%	0	1
LYCOPODIACEAE	LYCOPODIUM	1	.17%	0	0
MISCEL	UNKNOWN	3	.52%	0	1
MISCEL	INDET BIS	50	8.68%	6	11
MISCEL	INDETER.	3	.52%	0	1
MISCEL	MONOLETE SPO	2	.34%	0	1

FILE: O'HARA

18 PRINCIPAL OF 25 IDENTIFIED TAXA

SAMPLE: 27 - DEPTH: 142CM - DEPOSITION RATE: 9.4E-03 CM/YR - CONTAMINANT: 24980#

COMMENT: 1 CM ABOVE CONTACT

FAMILY	PRINCIPAL TAXA	COUNT	FREQ.	95%	CI	CONC.	INF.
PINACEAE	PINUS HAPL	23	1.79%	1	2	6178	58.5
PINACEAE	PINUS DIPL	8	.62%	0	1	2149	20.7
PINACEAE	PINUS	1068	83.24%	81	85	286867	2697
PINACEAE	ABIES	50	3.89%	2	5	13430	126.7
PINACEAE	PICEA	13	1.01%	0	1	3492	33.3
PINACEAE	LARIX/PSEU	1	.07%	0	0	269	3
PINACEAE	TSUGA	2	.15%	0	0	537	5.5
CUPRESSACEAE	JUNIPERUS	5	.38%	0	0	1343	13.1
BETULACEAE	ALNUS	67	5.22%	4	6	17996	169.6
SALICACEAE	SALIX	1	.07%	0	0	269	3
GRAMINEAE	GRAMINEAE	6	.46%	0	1	1612	15.6
CYPERACEAE	CYPERACEAE	5	.38%	0	0	1343	13.1
COMPOSITAE	ARTEMISIA	27	2.1%	1	3	7252	68.6
COMPOSITAE	TUBULIFL H.S.	1	.07%	0	0	269	3
CHENO-AM	CHENO-AM	3	.23%	0	0	806	8
CHENO-AM	SARCOBATUS	1	.07%	0	0	269	3
ELAEAGNACEAE	SHEPHERDIA CAN	1	0.7%	0	0	269	3
LEGUMINOSAE	ASTRAGALUS	1	0.7%	0	0	269	3

SUM

1283#

CONTAM. COUNT: 93 #

CONCENTRATION: 344617#/CM3

INFLUX: 3239#/CM2/YR

FAMILY	EXCLUDED TAXA	COUNT	FREQ.	95%	CI
SELAGINELLACEAE	SELAGINELLA	4	.31%	0	0
LYCOPODIACEAE	LYCOPODIUM	1	.07%	0	0
POLYPODIACEAE	PTERIDIUM	2	.15%	0	0
MISCEL	INDETER	7	.54%	0	1
MISCEL	INDET BIS	133	10.36%	8	12
MISCEL	UNKNOWN	3	.23%	0	0
POLYPODIACEAE	DRYOPTERIS	3	.23%	0	0

FILE: O'HARA

16 PRINCIPAL OF 26 IDENTIFIED TAXA

SAMPLE: 27 - DEPTH: 140CM - DEPOSITION RATE: 9.4E-03 CM/YR - CONTAMINANT: 24980#

COMMENT: NONE

FAMILY	PRINCIPAL TAXA	COUNT	FREQ.	95%	CI	CONC.	INF.
PINACEAE	PINUS HAPL	27	2.19%	1	3	18229	171.8
PINACEAE	PINUS DIPL	8	.65%	0	1	5401	51.2
PINACEAE	PINUS	954	77.56%	75	79	644079	6054.8
PINACEAE	ABIES	44	3.57%	2	4	29706	279.7
PINACEAE	PICEA	11	.89%	0	1	7426	70.3
CUPRESSACEAE	JUNIPERUS	9	.73%	0	1	6076	57.6
BETULACEAE	ALNUS	133	10.81%	9	12	89793	844.5
BETULACEAE	BETULA	6	.48%	0	1	4051	38.5
SALICACEAE	SALIX	2	.16%	0	0	1350	13.1
GRAMINEAE	GRAMINEAE	3	.24%	0	0	2025	19.5
CYPERACEAE	CYPERACEAE	4	.32%	0	0	2701	25.8
COMPOSITAE	ARTEMISIA	19	1.54%	0	2	12828	121
CHENO-AM	CHENO-AM	6	.48%	0	1	4051	38.5
CHENO-AM	SARCOBATUS	1	.08%	0	0	675	6.8
ELAEAGNACEAE	SHEPHERDIA CAN	2	.16%	0	0	1350	13.1
ERICALES	MONOTROPA	1	.08%	0	0	675	6.8

SUM

1230#

CONTAM. COUNT: 37 #

CONCENTRATION: 830416#/CM3

INFLUX: 7806#/CM2/YR

FAMILY	EXCLUDED TAXA	COUNT	FREQ.	95%	CI
SELAGINELLACEAE	SELAGINELLA	1	.08%	0	0
POLYPODIACEAE	DRYPOTERIS	6	.48%	0	1
POLYPODIACEAE	PTERIDIUM	3	.24%	0	0
LYCOPODIACEAE	LYCOPODIUM	1	.08%	0	0
MISCEL	INDETER	9	.73%	0	1
MISCEL	INDET BIS	111	9.02%	7	10
MISCEL	UNKNOWN	2	.16%	0	0
MISCEL	MONOLETE SPO	3	.24%	0	0
MISCEL	INAPERTURATE SPO	7	.56%	0	1
POLYPODIACEAE	ATHYRIUM	1	.08%	0	0

FILE: O'HARA

20 PRINCIPAL OF 27 IDENTIFIED TAXA

SAMPLE: 26 - DEPTH: 135CM - DEPOSITION RATE: 9.4E-03 CM/YR - CONTAMINANT: 24980#

COMMENT: NONE

FAMILY	PRINCIPAL TAXA	COUNT	FREQ.	95%	CI	CONC.	INF.
PINACEAE	PINUS HAPL	39	3.2%	2	4	26330	248
PINACEAE	PINUS DIPL	12	.98%	0	1	8102	76.6
PINACEAE	PINUS	900	73.95%	71	76	607622	5712.1
PINACEAE	ABIES	58	4.76%	3	6	39158	368.5
PINACEAE	PICEA	20	1.64%	1	2	13503	127.4
PINACEAE	TSUGA	2	.16%	0	0	1350	13.1
PINACEAE	LARIX/PSEU	1	.08%	0	0	675	6.8
RANUNCULACEAE	DELPHINIUM	1	.08%	0	0	675	6.8
CUPRESSACEAE	JUNIPERUS	3	.24%	0	0	2025	19.5
BETULACEAE	ALNUS	120	9.86%	8	11	81016	762
BETULACEAE	BETULA	7	.57%	0	1	4726	44.9
SALICACEAE	SALIX	2	.16%	0	0	1350	13.1
GRAMINEAE	GRAMINEAE	15	1.23%	0	2	10127	95.6
CYPERACEAE	CYPERACEAE	5	.41%	0	0	3376	32.2
COMPOSITAE	ARTEMISIA	20	1.64%	1	2	13503	127.4
CHENO-AM	CHENO-AM	2	.16%	0	0	1350	13.1
CHENO-AM	SARCOBATUS	1	.08%	0	0	675	6.8
ELAEAGNACEAE	SHEPHERDIA CAN	1	.08%	0	0	675	6.8
CORNACEAE	CORNUS CAN	4	.32%	0	0	2701	25.8
LORANTHACEAE	ARCEUTHOBIMUM	4	.32%	0	0	2701	25.8

SUM		1217#					
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CONTAM. COUNT: 37 #

CONCENTRATION: 821639#/CM3

INFLUX: 7723#/CM2/YR

FAMILY	EXCLUDED TAXA	COUNT	FREQ.	95%	CI
POLYPODIACEAE	DRYOPTERIS	6	.49%	0	1
POLYPODIACEAE	PTERIDIUM	6	.49%	0	1
SELAGINELLACEAE	SELAGINELLA	2	.16%	0	0
MISCEL	INDETER.	6	.49%	0	1
MISCEL	INDET BIS	57	4.68%	3	6
MISCEL	UNKNOWN	6	.49%	0	1
MISCEL	INAPERTURATE SPO	7	.57%	0	1

FILE: O'HARA

16PRINCIPAL OF 24 IDENTIFIED TAXA

SAMPLE: 25 - DEPTH: 130CM - DEPOSITION RATE: 9.4E-03 CM/YR - CONTAMINANT: 24980#

COMMENT: NONE

FAMILY	PRINCIPAL TAXA	COUNT	FREQ.	95%	CI	CONC.	INF.
PINACEAE	PINUS HAPL	35	3.28%	2	4	39741	374
PINACEAE	PINUS DIPL	8	.74%	0	1	9084	85.8
PINACEAE	PINUS	840	78.72%	76	81	8966	83.1
PINACEAE	PICEA	9	.84%	0	1	10219	96.5
PINACEAE	ABIES	44	4.12%	3	5	49960	470.1
RANUNCULACEAE	DELPHINIUM	1	.09%	0	0	1135	11.1
CUPRESSACEAE	JUNIPERUS	1	.09%	0	0	1135	11.1
BETULACEAE	ALNUS	87	8.15%	6	9	98785	929
BETULACEAE	BETULA	6	.56%	0	1	6813	64.5
GRAMINEAE	GRAMINEAE	8	.74%	0	1	9084	85.8
CYPERACEAE	CYPERACEAE	3	.28%	0	0	3406	32.5
COMPOSITAE	ARTEMISIA	14	1.31%	0	2	15896	149.9
COMPOSITAE	FRANSERIA	1	.09%	0	0	1135	11.1
CHENO-AM	CHENO-AM	5	.46%	0	1	5677	53.8
CORNACEAE	CORNUS CAN	3	.28%	0	0	3406	32.5
LORANTHACEAE	ARCEUTHOBIMUM	2	.18%	0	0	2271	21.8

SUM 1067#

CONTAM. COUNT: 22#

CONCENTRATION: 1211530#/CM3

INFLUX: 11388#/CM2/YR

FAMILY	EXCLUDED TAXA	COUNT	FREQ.	95%	CI
POLYPODIACEAE	DRYOPTERIS	9	.84%	0	1
POLYPODIACEAE	PTERIDIUM	9	.84%	0	1
SELAGINELLACEAE	SELAGINELLA	3	.28%	0	0
POLYPODIACEAE	ATHYRIUM	1	.09%	0	0
MISCEL	INDETER.	5	.46%	0	1
MISCEL	INDET BIS	46	4.31%	3	5
MISCEL	UNKNOWN	3	.28%	0	0
MISCEL	INAPERTURATE SPO	4	.37%	0	0

FILE: O'HARA

20 PRINCIPAL OF 30 IDENTIFIED TAXA

SAMPLE: 24 - DEPTH: 125CM - DEPOSITION RATE: 9.4E-03 CM/YR - CONTAMINANT: 24980#

COMMENT: NONE

FAMILY	PRINCIPAL TAXA	COUNT	FREQ.	95%	CI	CONC.	INF.
PINACEAE	PINUS HAPL	57	4.3%	3	5	67803	637.8
PINACEAE	PINUS DIPL	15	1.13%	0	1	17843	168.2
PINACEAE	PINUS	985	74.33%	71	76	1171681	11014.3
PINACEAE	ABIES	59	4.45%	3	5	70182	660.2
PINACEAE	PICEA	32	2.41%	1	3	38065	358.3
POLYGONACEAE	RUMEX	1	.07%	0	0	1190	11.6
CUPRESSACEAE	JUNIPERUS	3	.22%	0	0	3569	34
BETULACEAE	ALNUS	111	8.37%	7	9	132037	1241.6
BETULACEAE	BETULA	15	1.13%	0	1	17843	168.2
BETULACEAE	CORYLUS	1	.07%	0	0	1190	11.6
SALICACEAE	SALIX	1	.07%	0	0	1190	11.6
GRAMINEAE	GRAMINEAE	8	.6%	0	1	9516	89.9
CYPERACEAE	CYPERACEAE	5	.37%	0	0	5948	56.4
COMPOSITAE	ARTEMISIA	23	1.73%	1	2	27359	257.6
COMPOSITAE	LIGULIFLORAE	1	.07%	0	0	1190	11.6
COMPOSITAE	TUBULIFL H.S.	1	.07%	0	0	1190	11.6
CHENO-AM	CHENO-AM	4	.3%	0	0	4758	45.2
CORNACEAE	CORNUS CAN	1	.07%	0	0	1190	11.6
LILIACEAE	ALLIUM	1	.07%	0	0	1190	11.6
LEGUMINOSAE	TRIFOLIUM	1	.07%	0	0	1190	11.6

SUM 1325#

CONTAM. COUNT: 21#

CONCENTRATION: 1576119#/CM3

INFLUX.: 14816#/CM2/YR

FAMILY	EXCLUDED TAXA	COUNT	FREQ.	95%	CI
POLYPODIACEAE	DRYOPTERIS	9	.67%	0	1
POLYPODIACEAE	PTERIDIUM	6	.45%	0	0
SELAGINELLACEAE	SELAGINELLA	2	.15%	0	0
SPHAGNACEAE	SPHAGNUM	1	.07%	0	0
MISCEL	TRILETE SPO	3	.22%	0	0
MISCEL	MONOLETE SPO	2	.15%	0	0
MISCEL	INAPERTURATE SPO	3	.22%	0	0
MISCEL	INDETER.	10	.75%	0	1
MISCEL	INDET BIS	71	5.35%	0	1
MISCEL	UNKNOWN	4	.3%	0	0

FILE: O'HARA

17 PRINCIPAL OF 28 IDENTIFIED TAXA

SAMPLE: 23 - DEPTH: 120CM - DEPOSITION RATE: 9.4E-03 CM/YR. - CONTAMINANT: 24980#

COMMENT: NONE

FAMILY	PRINCIPAL TAXA	COUNT	FREQ.	95%	CI	CONC.	INF.
PINACEAE	PINUS HAPL	27	3.47%	2	5	17749	167.3
PINACEAE	PINUS DIPL	7	.9%	0	1	4602	43.7
PINACEAE	PINUS	620	79.79%	76	82	407568	3831.6
PINACEAE	ABIES	31	3.98%	2	5	20378	192
PINACEAE	PICEA	27	3.47%	2	5	17749	167.3
PINACEAE	LARIX/PSEU	1	.12%	0	0	657	6.6
CUPRESSACEAE	JUNIPERUS	2	.25%	0	0	1315	12.8
BETULACEAE	ALNUS	33	4.24%	3	5	21693	204.4
BETULACEAE	BETULA	4	.51%	0	1	2629	25.2
SALICACEAE	SALIX	2	.25%	0	0	1315	12.8
GRAMINEAE	GRAMINEAE	7	.9%	0	1	4602	43.7
CYPERACEAE	CYPERACEAE	3	.38%	0	1	1972	19
COMPOSITAE	ARTEMISIA	6	.77%	0	1	3944	37.5
COMPOSITAE	AMBROSIA	1	.12%	0	0	657	6.6
CHENO-AM	CHENO-AM	4	.51%	0	1	2629	25.2
LORANTHACEAE	ARCEUTHOBium	1	.12%	0	0	657	6.6
HALORAGIDACEAE	MYRIOPHYLLUM	1	.12%	0	0	657	6.6

SUM

777#

CONTAM. COUNT: 38#

CONCENTRATION: 510775#/CM3

INFLUX: 4801#/CM2/YR

FAMILY	EXCLUDED TAXA	COUNT	FREQ.	95%	CI
POLYPODIACEAE	DRYOPTERIS	9	1.15%	0	2
POLYPODIACEAE	PTERIDIUM	5	.64%	0	1
POLYPODIACEAE	ATHYRIUM	3	.38%	0	1
LYCOPODIACEAE	LYCOPODIUM	5	.64%	0	1
SPHAGNACEAE	SPHAGNUM	1	.12%	0	0
MISCEL	TRILETE SPO	4	.51%	0	1
MISCEL	MONOLETE SPO	10	1.28%	0	2
MISCEL	INAPERTURATE SPO	1	.12%	0	0
MISCEL	INDETER.	6	.77%	0	1
MISCEL	INDET BIS	40	5.14%	3	6
MISCEL	UNKNOWN	2	.25%	0	0

FILE: O'HARA

18 PRINCIPAL OF 29 IDENTIFIED TAXA

SAMPLE: 22- DEPTH: 115CM - DEPOSITION RATE: 9.4E-03 CM/YR - CONTAMINANT: 24980#

COMMENT: BASE OF MAZAMA

FAMILY	PRINCIPAL TAXA	COUNT	FREQ.	95%	CI	CONC.	INF.
PINACEAE	PINUS HAPL	29	3.3%	2	4	36221	340.9
PINACEAE	PINUS DIPL	9	1.02%	0	1	11241	106.1
PINACEAE	PINUS	580	66.05%	62	69	724420	6810
PINACEAE	ABIES	52	5.92%	4	7	64948	611
PINACEAE	PICEA	46	5.23%	3	6	57454	540.5
PINACEAE	LARIX/PSEU	4	.45%	0	1	4996	47.4
RANUNCULACEAE	THALICTRUM	1	.11%	0	0	1249	12.2
CUPRESSACEAE	JUNIPERUS	2	.22%	0	0	2498	23.9
BETULACEAE	ALNUS	95	10.82%	8	13	118655	1115.8
BETULACEAE	BETULA	19	2.16%	1	3	23731	223.5
SALICACEAE	SALIX	4	.45%	0	1	4996	47.4
GRAMINEAE	GRAMINEAE	6	.68%	0	1	7494	70.9
CYPERACEAE	CYPERACEAE	3	.34%	0	0	3747	35.7
COMPOSITAE	ARTEMISIA	18	2.05%	1	3	22482	211.8
COMPOSITAE	FRANSERIA	4	.45%	0	1	4996	47.4
CHENO-AM	CHENO-AM	3	.34%	0	0	3747	35.7
ELAEAGNACEAE	SHEPHERDIA CAN	2	.22%	0	0	2498	23.9
LORANTHACEAE	ARCEUTHOBium	1	.11%	0	0	1249	12.2

SUM 878#

CONTAM. COUNT: 20#

CONCENTRATION: 1096622#/CM3

INFLUX: 10308#/CM2/YR

FAMILY	EXCLUDED TAXA	COUNT	FREQ.	95%	CI
POLYPODIACEAE	DRYOPTERIS	5	.56%	0	1
POLYPODIACEAE	PTERIDIUM	4	.45%	0	1
POLYPODIACEAE	CYSTOPTERIS	2	.22%	0	0
LYCOPODIACEAE	LYCOPODIUM	4	.45%	0	1
MISCEL	TRILETE SPO	3	.34%	0	0
MISCEL	MONOLETE SPO	6	.68%	0	1
MISCEL	INAPERTURATE SPO	3	.34%	0	0
MISCEL	INDETER.	11	1.25%	0	2
MISCEL	INDET BIS	43	4.89%	3	6
MISCEL	UNKNOWN	3	.34%	0	0

FILE: O'HARA

14 PRINCIPAL OF 25 IDENTIFIED TAXA

SAMPLE: 21 - DEPTH: 105CM - DEPOSITION RATE: .0139CM/YR - CONTAMINANT: 24980#

COMMENT: ABOVE MAZAMA

FAMILY	PRINCIPAL TAXA	COUNT	FREQ.	95%	CI	CONC.	INF.
PINACEAE	PINUS HAPL	29	3.7%	2	5	10812	150.7
PINACEAE	PINUS DIPL	12	1.53%	0	2	4474	62.6
PINACEAE	PINUS	500	63.85%	60	67	186418	2591.7
PINACEAE	ABIES	37	4.72%	3	6	13795	192.2
PINACEAE	PICEA	46	5.87%	4	7	17150	238.8
PINACEAE	LARIX/PSEU	4	.51%	0	1	1491	21.2
BETULACEAE	ALNUS	107	13.66%	11	16	39893	555
BETULACEAE	BETULA	8	1.02%	0	2	2983	41.9
SALICACEAE	SALIX	2	.25%	0	0	746	10.8
GRAMINEAE	GRAMINEAE	11	1.4%	0	2	4101	57.5
CYPERACEAE	CYPERACEAE	1	.12%	0	0	373	5.6
COMPOSITAE	ARTEMISIA	20	2.55%	1	3	7457	104.1
COMPOSITAE	TUBULIFL H.S.	2	.25%	0	0	746	10.8
CHENO-AM	CHENO-AM	4	.51%	0	1	1491	21.2

SUM

783#

CONTAM. COUNT: 67#

CONCENTRATION: 291930#/CM3

INFLUX: 4058#/CM2/YR

FAMILY	EXCLUDED TAXA	COUNT	FREQ.	95%	CI
POLYPODIACEAE	DRYOPTERIS	4	.51%	0	1
POLYPODIACEAE	ATHYRIUM	3	.38%	0	1
POLYPODIACEAE	PTERIDIUM	4	.51%	0	1
SELACINELLACEAE	SELAGINELLA	2	.25%	0	0
LYCOPODIACEAE	LYCOPODIUM	4	.51%	0	1
MISCEL	TRILETE SPO	1	.12%	0	0
MISCEL	MONOLETE SPO	4	.51%	0	1
MISCEL	INAPERTURATE SPO	2	.25%	0	0
MISCEL	INDETER.	9	1.14%	0	2
MISCEL	INDET BIS	39	4.98%	3	6
MISCEL	UNKNOWN	1	.12%	0	0

FILE: O'HARA

18 PRINCIPAL OF 29 IDENTIFIED TAXA

SAMPLE: 20 - DEPTH: 100CM - DEPOSITION RATE: .0139 CM/YR - CONTAMINANT: 24980#

COMMENT: NONE

FAMILY	PRINCIPAL TAXA	COUNT	FREQ.	95%	CI	CONC.	INF.
PINACEAE	PINUS HAPL	16	2.44%	1	3	12112	168.8
PINACEAE	PINUS DIPL	24	3.66%	2	5	18167	253
PINACEAE	PINUS	400	61.16%	57	64	302788	4209.2
PINACEAE	ABIES	25	3.82%	2	5	18924	263.5
PINACEAE	PICEA	45	6.88%	5	9	34064	473.9
PINACEAE	LARIX/PSEU	3	.45%	0	1	2271	32
PINACEAE	TSUGA	2	.3%	0	1	1514	21.5
RANUNCULACEAE	THALICTRUM	2	.3%	0	1	1514	21.5
CUPRESSACEAE	JUNIPERUS	3	.45%	0	1	2271	32
BETULACEAE	ALNUS	91	13.91%	11	16	68884	957.9
BETULACEAE	BETULA	12	1.83%	1	3	9084	126.7
SALICACEAE	SALIX	4	.61%	0	1	3028	42.5
GRAMINEAE	GRAMINEAE	4	.61%	0	1	3028	42.5
CYPERACEAE	CYPERACEAE	6	.91%	0	1	4542	63.6
COMPOSITAE	ARTEMISIA	10	1.52%	0	2	7570	105.7
COMPOSITAE	TUBULIFL H.S.	2	.3%	0	1	1514	21.5
CHENO-AM	CHENON-AM	4	.61%	0	1	3028	42.5
ERICALES	ERICALES	1	.15%	0	0	757	11

SUM

654#

CONTAM. COUNT: 33#

CONCENTRATION: 495058#/CM3

INFLUX: 6881#/CM2/YR

FAMILY	EXCLUDED TAXA	COUNT	FREQ.	95%	CI
SELAGINELLACEAE	SELAGINELLA	1	.15%	0	0
POLYPODIACEAE	DRYOPTERIS	4	.61%	0	1
POLYPODIACEAE	PTERIDIUM	4	.61%	0	1
POLYPODIACEAE	ATHYRIUM	1	.15%	0	0
LYCOPODIACEAE	LYCOPODIUM	3	.45%	0	1
MISCEL	TRILETE SPO	3	.45%	0	1
MISCEL	MONOLETE SPO	8	1.22%	0	2
MISCEL	INAPERTURATE SPO	2	.3%	0	1
MISCEL	INDETER.	7	1.07%	0	2
MISCEL	INDET BIS	37	5.65%	4	7
MISCEL	UNKNOWN	1	.15%	0	0

FILE: O'HARA

20 PRINCIPAL OF 30 IDENTIFIED TAXA

SAMPLE: 19 - DEPTH: 095CM - DEPOSITION RATE: .0139 CM/YR - CONTAMINANT: 24980#

COMMENT: NONE

FAMILY	PRINCIPAL TAXA	COUNT	FREQ.	95%	CI	CONC.	INF.
PINACEAE	PINUS HAPL	12	2.23%	1	3	5081	71.1
PINACEAE	PINUS DIPL	17	3.17%	1	5	7198	100.5
PINACEAE	PINUS	350	65.29%	61	69	148186	2060.2
PINACEAE	ABIES	28	5.22%	3	7	11855	165.2
PINACEAE	PICEA	48	8.95%	6	11	20323	282.9
PINACEAE	LARIX/PSEU	2	.37%	0	1	847	12.2
PINACEAE	TSUGA	2	.37%	0	1	847	12.2
SAXIFRAGACEAE	SAXIFRAGA	2	.37%	0	1	847	12.2
CUPRESSACEAE	JUNIPERUS	3	.55%	0	1	1270	18.1
BETULACEAE	ALNUS	52	9.7%	7	12	22016	306.5
BETULACEAE	BETULA	5	.93%	0	2	2117	29.9
BETULACEAE	CORYLUS	1	.18%	0	1	423	6.3
SALICACEAE	SALIX	1	.18%	0	1	423	6.3
GRAMINEAE	GRAMINEAE	1	.18%	0	1	423	6.3
CYPERACEAE	CYPERACEAE	3	.55%	0	1	1270	18.1
COMPOSITAE	ARTEMISIA	3	.55%	0	1	1270	18.1
COMPOSITAE	TUBULIFL H.S.	1	.18%	0	1	423	6.3
CHENO-AM	CHENO-AM	2	.37%	0	1	847	12.2
ELEAEGNACEAE	SHEPHERDIA CAN	1	.18%	0	1	423	6.3
LORANTHACEAE	ARCEUTHOBium	2	.37%	0	1	847	12.2

SUM	536#
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CONTAM. COUNT: 59#

CONCENTRATION: 226937#/CM3

INFLUX: 3154#/CM2/YR

FAMILY	EXCLUDED TAXA	COUNT	FREQ.	95%	CI
MISCEL	TRILETE SPO	5	.93%	0	2
MISCEL	MONOLETE SPO	9	1.67%	0	3
MISCEL	INAPERTURATE SPO	3	.55%	0	1
POLYPODIACEAE	DRYOPTERIS	5	.93%	0	2
POLYPODIACEAE	PTERIDIUM	4	.74%	0	1
SELAGINELLACEAE	SELAGINELLA	1	.18%	0	1
LYCOPODIACEAE	LYCOPODIUM	3	.55%	0	1
MISCEL	INDETER.	4	.74%	0	1
MISCEL	INDET BIS	39	7.27%	5	9
MISCEL	UNKNOWN	4	.74%	0	1

FILE: O'HARA

20 PRINCIPAL OF 32 IDENTIFIED TAXA

SAMPLE: 18 - DEPTH: 090CM - DEPOSITION RATE: .0139 CM/YR - CONTAMINANT: 24980#

COMMENT: NONE

FAMILY	PRINCIPAL TAXA	COUNT	FREQ.	95%	CI	CONC.	INF.
PINACEAE	PINUS HAPL	19	2.72%	1	4	18255	254.2
PINACEAE	PINUS DIPL	28	4.02%	2	5	26902	374.4
PINACEAE	PINUS	370	53.16%	49	56	355485	4941.7
PINACEAE	ABIES	53	7.61%	5	9	50921	708.3
PINACEAE	PICEA	70	10.05%	8	12	67254	935.3
PINACEAE	LARIX/PSEU	3	.43%	0	1	2882	40.5
RANUNCULACEAE	THALICTRUM	2	.28%	0	1	1922	27.2
CUPRESSACEAE	JUNIPERUS	4	.57%	0	1	3843	53.9
BETULACEAE	ALNUS	96	13.79%	11	16	92234	1282.5
BETULACEAE	BETULA	11	1.58%	0	2	10568	147.3
SALICACEAE	SALIX	2	.28%	0	1	1922	27.2
GRAMINEAE	GRAMINEAE	5	.71%	0	1	4804	67.2
CYPERACEAE	CYPERACEAE	5	.71%	0	1	4804	67.2
COMPOSITAE	ARTEMISIA	16	2.29%	1	3	15372	214.1
COMPOSITAE	TUBULIFL H.S.	1	.14%	0	0	961	13.8
COMPOSITAE	AMBROSIA	2	.28%	0	1	1922	27.2
CHENO-AM	CHENO-AM	5	.71%	0	1	4804	67.2
CORNACEAE	CORNUS CAN	1	.14%	0	0	961	13.8
CARYOPHYLLACEAE	CARYOPHYLLACEAE	1	.14%	0	0	961	13.8
ERICALES	ERICALES	2	.28%	0	1	1922	27.2

SUM 696#

CONTAM. COUNT: 26#

CONCENTRATION: 668695#/CM3

INFLUX: 9295#/CM2/YR

FAMILY	EXCLUDED TAXA	COUNT	FREQ.	95%	CI
EQUISETACEAE	EQUSETUM	1	.14%	0	0
MISCEL	TRILETE SPO	3	.43%	0	1
MISCEL	MONOLETE SPO	7	1.0%	0	2
MISCEL	INAPERTURATE SPO	1	.14%	0	0
POLYPODIACEAE	DRYOPTERIS	1	.14%	0	0
POLYPODIACEAE	PTERIDIUM	1	.14%	0	0
POLYPODIACEAE	ATHYRIUM	1	.14%	0	0
SELAGINELLACEAE	SELAGINELLA	1	.14%	0	0
LYCOPODIACEAE	CYCOPOCIUM	3	.43%	0	1
MISCEL	INDETER.	6	.86%	0	1
MISCEL	INDET BIS	34	4.88%	3	6
MISCEL	UNKNOWN	1	.14%	0	0

FILE: O'HARA

16 PRINCIPAL OF 24 IDENTIFIED TAXA

SAMPLE: 17 - DEPTH: 085CM - DEPOSITION RATE: .0139 CM/YR - CONTAMINANT: 24980#

COMMENT: NONE

FAMILY	PRINCIPAL TAXA	COUNT	FREQ.	95%	CI	CONC.	INF.
PINACEAE	PINUS HAPL	25	3.62%	2	5	10408	145.1
PINACEAE	PINUS DIPL	27	3.91%	2	5	11241	156.7
PINACEAE	PINUS	380	55.15%	51	58	158207	2199.5
PINACEAE	ABIES	41	5.95%	4	7	17070	237.7
PINACEAE	PICEA	92	13.35%	11	16	38303	532.9
PINACEAE	LARIX/PSEU	1	.14%	0	0	416	6.2
RANUNCULACEAE	THALICTRUM	1	.14%	0	0	416	6.2
BETULACEAE	ALNUS	87	12.62%	10	15	36221	503.9
BETULACEAE	BETULA	9	1.3%	0	2	3747	52.5
GRAMINEAE	GRAMINEAE	2	.29%	0	1	833	12
CYPERACEAE	CYPERACEAE	7	1.01%	0	2	2914	41
COMPOSITAE	ARTEMISIA	11	1.59%	0	2	4580	64.1
COMPOSITAE	TUBULIFL H.S.	2	.29%	0	1	833	12
CHENO-AM	CHENO-AM	2	.29%	0	1	833	12
CORNACEAE	CORNUS CAN	1	.14%	0	0	416	6.2
UMBELLIFERAE	HERACLEUM	1	.14%	0	0	416	6.2

SUM 689#

CONTAM. COUNT: 60#

CONCENTRATION: 286854#/CM3

INFLUX: 3987#/CM2/YR

FAMILY	EXCLUDED TAXA	COUNT	FREQ.	95%	CI
MISCEL	MONOLETE SPO	3	.43%	0	1
MISCEL	INDETER.	5	.72%	0	1
MISCEL	UNKNOWN	3	.43%	0	1
MISCEL	INDET BIS	39	5.66%	4	7
SELAGINELLACEAE	SELAGINELLA	2	.29%	0	1
POLYPODIACEAE	DRYOPTERIS	4	.58%	0	1
POLYPODIACEAE	ATHYRIUM	6	.87%	0	1
LYCOPODIACEAE	LYCOPODIUM	8	1.16%	0	2

FILE: O'HARA

20 PRINCIPAL OF 30 IDENTIFIED TAXA

SAMPLE: 16 - DEPTH: 080CM - DEPOSITION RATE: .0139 CM/YR - CONTAMINANT: 24980#

COMMENT: NONE

FAMILY	PRINCIPAL TAXA	COUNT	FREQ.	95%	CI	CONC.	INF.
PINACEAE	PINUS HAPL	21	3.33%	2	5	14572	203
PINACEAE	PINUS DIPL	29	4.61%	3	6	20123	280.2
PINACEAE	PINUS	318	50.55%	46	54	220657	3067.6
PINACEAE	ABIES	23	3.65%	2	5	15959	222.3
PINACEAE	PICEA	98	15.58%	12	18	68001	945.7
PINACEAE	LARIX/PSEU	4	.63%	0	1	2776	39
POLYGONACEAE	ERIGONUM	2	.31%	0	1	1388	19.7
RANUNCULACEAE	THALICTRUM	1	.15%	0	0	694	10.1
ROSACEAE	POTENTILLA	1	.15%	0	0	694	10.1
BETULACEAE	ALNUS	104	16.53%	13	19	72164	1003.5
BETULACEAE	BETULA	6	.95%	0	2	4163	58.3
SALICACEAE	SALIX	1	.15%	0	0	694	10.1
GRAMINEAE	GRAMINEAE	6	.95%	0	2	4163	58.3
COMPOSITAE	ARTEMISIA	6	.95%	0	2	4163	58.3
COMPOSITAE	TUBULIFL H.S.	1	.15%	0	0	694	10.1
COMPOSITAE	FRANSERIA	1	.15%	0	0	694	10.1
CHENO-AM	CHENO-AM	4	.63%	0	1	2776	39
ELAEAGNACEAE	SHEPHERDIA CAN	1	.15%	0	0	694	10.1
CORNACEAE	CORNUS CAN	1	.15%	0	0	694	10.1
SCROPHULARIACEAE	PENSTEMON	1	.15%	0	0	694	10.1

SUM

629#

CONTAM. COUNT: 60#

CONCENTRATION: 436456#/CM3

INFLUX: 6067#/CM2/YR

FAMILY	EXCLUDED TAXA	COUNT	FREQ.	95%	CI
MISCEL	INDETER.	8	1.27%	0	2
MISCEL	UNKNOWN	2	.31%	0	1
MISCEL	INDET BIS	48	7.63%	5	9
MISCEL	MONOLETE SPO	3	.47%	0	1
MISCEL	TRILETE SPO	2	.31%	0	1
MISCEL	INAPERTURATE	1	.15%	0	0
LYCOPODIACEAE	LYCOPODIUM	1	.15%	0	0
POLYPODIACEAE	DRYOPTERIS	4	.63%	0	1
POLYPODIACEAE	PTERIDIUM	3	.47%	0	1
POLYPODIACEAE	ATHYRIUM	2	.31%	0	1

FILE: O'HARA

21 PRINCIPAL OF 33 IDENTIFIED TAXA

SAMPLE: 15 - DEPTH: 075CM - DEPOSITION RATE: .0139 CM/YR - CONTAMINANT: 24980#

COMMENT: NONE

FAMILY	PRINCIPAL TAXA	COUNT	FREQ.	95%	CI	CONC.	INF.
PINACEAE	PINUS HAPL	16	2.57%	1	4	12112	168.8
PINACEAE	PINUS DIPL	39	6.27%	4	8	29522	410.8
PINACEAE	PINUS	284	45.65%	41	49	214979	2988.7
PINACEAE	ABIES	21	3.37%	2	5	15896	221.4
PINACEAE	PICEA	110	17.68%	14	20	83267	1157.9
PINACEAE	LARIX/PSEU	5	.8%	0	1	3785	53.1
RANUNCULACEAE	THALICTRUM	4	.64%	0	1	3028	42.5
CUPRESSACEAE	JUNIPERUS	2	.32%	0	1	1514	21.5
BETULACEAE	ALNUS	110	17.68%	14	20	83267	1157.9
BETULACEAE	BETULA	7	1.12%	0	2	5299	74.1
SALICACEAE	SALIX	2	.32%	0	1	1514	21.5
GRAMINEAE	GRAMINEAE	6	.96%	0	2	4542	63.6
CYPERACEAE	CYPERACEAE	2	.32%	0	1	1514	21.5
COMPOSITAE	ARTIMISIA	6	.96%	0	2	4542	63.6
COMPOSITAE	FRANSERIA	1	.16%	0	0	757	11
COMPOSITAE	TUBULIFL H.S.	1	.16%	0	0	757	11
CHENO-AM	CHENO-AM	1	.16%	0	0	757	11
ELAEAGNACEAE	SHEPHERDIA CAN	2	.32%	0	1	1514	21.5
CORNACEAE	CORNUS CAN	1	.16%	0	0	757	11
LORANTHACEAE	ARCEUTHOBium	1	.16%	0	0	757	11
CARYOPHYLLACEAE	CARYOPHYLLACEAE	1	.16%	0	0	757	11
SUM		622#					

CONTAM. COUNT: 33#

CONCENTRATION: 470835#/CM3

INFLUX: 6545#/CM2/YR

FAMILY	EXCLUDED TAXA	COUNT	FREQ.	95%	CI
MISCEL	MONOLETE SPO	5	.8%	0	1
MISCEL	TRILETE SPO	2	.32%	0	1
MISCEL	INAPERTURATE SPO	1	.16%	0	0
LYCOPODIACEAE	LYCOPodium	1	.16%	0	0
POLYPODIACEAE	DRYOPTERIS	4	.64%	0	1
POLYPODIACEAE	PTERIDIUM	2	.32%	0	1
POLYTODIACEAE	ATHYRIUM	4	.64%	0	1
SELAGINELLACEAE	SELAGINELLA	1	.16%	0	0
EQUISETACEAE	EQUISETUM	3	.48%	0	1
MISCEL	INDETER.	8	1.28%	0	2
MISCEL	UNKNOWN	4	.64%	0	1
MISCEL	INDET BIS	37	5.94%	4	8

FILE: O'HARA

18 PRINCIPAL OF 28 IDENTIFIED TAXA

SAMPLE: 14 - DEPTH: 070CM - DEPOSITION RATE: .0139 CM/YR - CONTAMINANT: 24980#

COMMENT: NONE

FAMILY	PRINCIPAL TAXA	COUNT	FREQ.	95%	CI	CONC.	INF.
PINACEAE	PINUS HAPL	20	2.78%	1	4	17843	248.5
PINACEAE	PINUS DIPL	39	5.43%	3	7	34794	484.1
PINACEAE	PINUS	353	49.16%	45	52	314926	4377.9
PINACEAE	ABIES	36	5.01%	3	6	32117	446.9
PINACEAE	PICEA	118	16.43%	13	19	105273	1463.7
PINACEAE	LARIX/PSEU	4	.55%	0	1	3569	50.1
PINACEAE	TSUGA	2	.27%	0	1	1784	25.2
POLYGONACEAE	POLYGONI BIS	1	.13%	0	0	892	12.8
BETULACEAE	ALNUS	113	15.73%	13	18	100812	1401.7
BETULACEAE	BETULA	13	1.81%	1	3	11598	161.7
GRAMINAE	GRAMINAE	6	.83%	0	1	5353	74.9
CYPERACEAE	CYPERACEAE	2	.27%	0	1	1784	25.2
COMPOSITAE	ARTEMISIA	5	.69%	0	1	4461	62.5
COMPOSITAE	FRANSERIA	1	.13%	0	0	892	12.8
CHENO-AM	CHENO-AM	1	.13%	0	0	892	12.8
CORNACEAE	CORNUS CAN	2	.27%	0	1	1784	25.2
CARYOPHYLLACEAE	CARYOPHYLLACEAE	1	.13%	0	0	892	12.8
UMBELLIFERAE	HERACLEUM	1	.13%	0	0	892	12.8

SUM

718#

CONTAM. COUNT: 28#

CONCENTRATION: 640559#/CM3

INFLUX: 8904#/CM2/YR

FAMILY	EXCLUDED TAXA	COUNT	FREQ.	95%	CI
MISCEL	MONOLETE SPO	4	.55%	0	1
MISCEL	TRILETE SPO	1	.13%	0	0
MISCEL	INAPERTURATE SPO	1	.13%	0	0
LYCOPODIACEAE	LYCOPODIUM	3	.41%	0	1
POLYPODIACEAE	DRYOPTERIS	4	.55%	0	1
POLYPODIACEAE	ATHYRIUM	1	.13%	0	0
EQUISETACEAE	EQUISETUM	1	.13%	0	0
MISCEL	INDETER.	9	1.25%	0	2
MISCEL	UNKNOWN	7	.97%	0	1
MISCEL	INDET BIS	64	8.91%	7	11

FILE: O'HARA

19 PRINCIPAL OF 28 IDENTIFIED TAXA

SAMPLE: 13 - DEPTH: 065CM - DEPOSITION RATE: .0139 CM/YR - CONTAMINANT: 24980#

COMMENT: NONE

FAMILY	PRINCIPAL TAXA	COUNT	FREQ.	95%	CI	CONC.	INF.
PINACEAE	PINUS HAPL	10	1.32%	0	2	5315	74.3
PINACEAE	PINUS DIPL	53	7.04%	5	9	28169	392.
PINACEAE	PINUS	356	47.34%	43	50	189210	2630.5
PINACEAE	ABIES	45	5.98%	4	7	23917	332.9
PINACEAE	PICEA	159	21.14%	18	24	84507	1175.1
PINACEAE	LARIX/PSEU	4	.53%	0	1	2126	30
PINACEAE	TSUGA	5	.66%	0	1	2657	37.4
RANUNCULACEAE	THALICTRUM	1	.13%	0	0	531	7.8
BETULACEAE	ALNUS	88	11.7%	9	14	46771	650.6
BETULACEAE	BETULA	3	.39%	0	1	1594	22.6
GRAMINEAE	GRAMINEAE	8	1.06%	0	2	4552	59.6
CYPERACEAE	CYPERACEAE	3	.39%	0	1	1594	22.6
COMPOSITAE	ARTEMISIA	4	.53%	00	1	2126	30
COMPOSITAE	TUBULIFL J.S.	1	.13%	0	0	531	7.8
COMPOSITAE	FRANSERIA	1	.13%	0	0	531	7.8
CHENO-AM	CHENO-AM	6	.79%	0	1	3189	44.8
CORNACEAE	CORNUS CAN	2	.26%	0	0	1063	15.2
LORANTHACEAE	ARCEUTHOBIMUM	1	.13%	0	0	531	7.8
ERICALES	ERICALES	2	.26%	0	0	1063	15.2

SUM	752#
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CONTAM. COUNT: 47#

CONCENTRATION: 399680#/CM3

INFLUX: 5556#/CM2/YR

FAMILY	EXCLUDED TAXA	COUNT	FREQ.	95%	CI
MISCEL	MONOLETE SPO	2	.26%	0	0
MISCEL	TRILETE SPO	1	.13%	0	0
LYCOPODIACEAE	LYCOPODIUM	5	.66%	0	1
POLYPODIACEAE	DRYOPTERIS	6	.79%	0	1
POLYPODIACEAE	ATHYRIUM	5	.66%	0	1
POLYPODIACEAE	PTERIDIUM	3	.39%	0	1
MISCEL	INDETER.	7	.93%	0	1
MISCEL	UNKNOWN	2	.26%	0	0
MISCEL	INDET BIS	57	7.57%	5	9

FILE: O'HARA

19 PRINCIPAL OF 30 IDENTIFIED TAXA

SAMPLE: 12 - DEPTH: 006CM - DEPOSITION RATE: .0139 CM/YR - CONTAMINANT: 24980#

COMMENT: NONE

FAMILY	PRINCIPAL TAXA	COUNT	FREQ.	95%	CI	CONC.	INF.
PINACEAE	PINUS HAPL	7	1.13%	0	2	3643	51.1
PINACEAE	PINUS DIPL	38	6.15%	4	8	19776	275.3
PINACEAE	PINUS	324	52.51%	48	56	168615	2344.2
PINACEAE	ABIES	27	4.37%	3	6	14051	195.8
PINACEAE	PICEA	127	20.58%	17	23	66093	919.1
PINACEAE	LARIX/PSEU	1	.16%	0	0	520	7.7
PINACEAE	TSUGA	2	.32%	0	1	1041	14.9
RANUNCULACEAE	THALICTRUM	2	.32%	0	1	1041	14.9
BETULACEAE	ALNUS	56	9.07%	7	11	29143	405.5
BETULACEAE	BETULA	2	.32%	0	1	1041	14.9
BETULACEAE	CORYLUS	1	.16%	0	0	520	7.7
GRAMINEAE	GRAMINEAE	7	1.13%	0	2	3643	51.1
CYPERACEAE	CYPERACEAE	5	.81%	0	1	2602	36.6
COMPOSITAE	ARTEMISIA	9	1.45%	0	2	4684	65.6
COMPOSITAE	TUBULIFL H.S.	2	.32%	0	1	1041	14.9
COMPOSITAE	AMBROSIA	1	.16%	0	0	520	7.7
CHENO-AM	CHENO-AM	4	.64%	0	1	2082	29.4
CORNACEAE	CORNUS CAN	1	.16%	0	0	520	7.7
ONAGRACEAE	EPILOBIUM	1	.16%	0	0	520	7.7

SUM

617#

CONTAM. COUNT: 48#

CONCENTRATION: 321097#/CM3

INFLUX: 4463#/CM2/YR

FAMILY	EXCLUDED TAXA	COUNT	FREQ.	95%	CI
EQUISETACEAE	EQUISETUM	2	.32%	0	1
MISCEL	MONOLETE	2	.32%	0	1
MISCEL	TRILETE SPO	3	.48%	0	1
MISCEL	INAPERTURATE SPO	11	.16%	0	0
LYCOPODIACEAE	LYCOPODIUM	5	.81%	0	1
POLYPODIACEAE	DRYOPTERIS	7	1.13%	0	2
POLYPODIACEAE	ATHYRIUM	1	.16%	0	0
POLYPODIACEAE	PTERIDIUM	2	.32%	0	1
MISCEL	INDETER.	9	1.45%	0	2
MISCEL	UNKNOWN	6	.97%	0	2
MISCEL	INDET BIS	41	6.64%	4	8

FILE: O'HARA

17 PRINCIPAL OF 27 IDENTIFIED TAXA

SAMPLE: 11 - DEPTH: 055CM - DEPOSITION RATE: .0139 CM/YR - CONTAMINANT: 24980#

COMMENT: NONE

FAMILY	PRINCIPAL TAXA	COUNT	FREQ.	95%	CI	CONC.	INF.
PINACEAE	PINUS HAPL	13	1.99%	1	3	10148	141.5
PINACEAE	PINUS DIPL	73	11.19%	8	13	56986	792.6
PINACEAE	PINUS	342	52.45%	48	56	266974	3711.4
PINACEAE	ABIES	29	4.44%	3	6	22638	315.1
PINACEAE	PICEA	105	16.1%	13	19	81966	1139.8
PINACEAE	LARIX/PSEU	3	.46%	0	1	2342	33
PINACEAE	TSUGA	2	.3%	0	1	1561	22.1
RANUNCULACEAE	THALICTRUM	1	.15%	0	0	781	11.3
BETULACEAE	ALNUS	61	9.35%	7	11	47618	662.3
BETULACEAE	BETULA	3	.46%	0	1	2342	33
SALICACEAE	SALIX	2	.3%	0	1	1561	22.1
GRAMINEAE	GRAMINEAE	6	.92%	0	1	4684	65.6
CYPERACEAE	CYPERACEAE	1	.15%	0	0	781	11.3
COMPOSITAE	ARTEMISIA	7	1.07%	0	2	5464	76.4
CHENO-AM	CHENO-AM	2	.3%	0	1	1561	22.1
CARYOPHYLLACEAE	CARYOPHYLLACEAE	1	.15%	0	0	781	11.3
LILIACEAE	LILIACEAE	1	.15%	0	0	781	11.3

SUM 652#

CONTAM. COUNT: 32#

CONCENTRATION: 508968#/CM3

INFLUX: 7075#/CM2/YR

FAMILY	EXCLUDED TAXA	COUNT	FREQ.	95%	CI
EQUISETACEAE	EQUISETUM	1	.15%	0	0
MISCEL	MONOLET SPO	1	.15%	0	0
LYCOPODIACEAE	LYCOPodium	2	.3%	0	1
POLYPODIACEAE	DRYOPTERIS	1	.15%	0	0
POLYPODIACEAE	ATHYRIUM	5	.76%	0	1
POLYPODIACEAE	PTERIDIUM	1	.15%	0	0
SELAGINELLACEAE	SELAGINELLA	1	.15%	0	0
MISCEL	INDETER.	5	.76%	0	1
MISCEL	UNKNOWN	3	.46%	0	1
MISCEL	INDET BIS	29	4.44%	3	6

FILE: O'HARA

20 PRINCIPAL OF 30 IDENTIFIED TAXA

SAMPLE: 10 - DEPTH: 050CM - DEPOSITION RATE: .0139 CM/YR - CONTAMINANT: 24980#

COMMENT: NONE

FAMILY	PRINCIPAL TAXA	COUNT	FREQ.	95%	CI	CONC.	INF.
PINACEAE	PINUS HAPL	10	1.59%	0	2	5430	75.9
PINACEAE	PINUS DIPL	58	9.23%	7	11	31497	438.3
PINACEAE	PINUS	302	48.08%	44	51	163999	2280
PINACEAE	ABIES	29	4.61%	3	6	15748	219.3
PINACEAE	PICEA	110	17.51%	14	20	59735	830.8
PINACEAE	LARIX/PSEU	1	.15%	0	0	543	8
PINACEAE	TSUGA	2	.31%	0	1	1086	15.5
POLYGONACEAE	OXYRIA	1	.15%	0	0	543	8
RANUNCULACEAE	THALICTRUM	1	.15%	0	0	543	8
SAXIFRAGACEAE	HEUCHERA	1	.15%	0	0	543	8
BETULACEAE	ALNUS	86	13.69%	11	16	46702	649.6
BETULACEAE	BETULA	6	.95%	0	2	3258	45.7
SALICACEAE	SALIX	1	.15%	0	0	543	8
GRAMINEAE	GRAMINEAE	7	1.11%	0	2	3801	53.3
COMPOSITAE	ARTEMISIA	6	.95%	0	2	3258	45.7
COMPOSITAE	AMBROSIA	1	.15%	0	0	543	8
COMPOSITAE	TUBULIFL H.S.	1	.15%	0	0	543	8
CHENO-AM	CHENO-AM	2	.31%	0	1	1086	15.5
ERICALES	ERICALES	2	.31%	0	1	1086	15.5
TYPHACEAE	TYPHA	1	.15%	0	0	543	8
SUM		628#					

CONTAM. COUNT: 46#

CONCENTRATION: 341031#/CM3

INFLUX: 4740#/CM2/YR

FAMILY	EXCLUDED TAXA	COUNT	FREQ.	95%	CI
MISCEL	TRILETE SPO	3	.47%	0	1
MISCEL	INAPERTURATE SPO	1	.15%	0	0
LYCOPODIACEAE	LYCOPODIUM	4	.63%	0	1
POLYPODIACEAE	DRYOPTERIS	1	.15%	0	0
POLYPODIACEAE	ATHYRIUM	4	.63%	0	1
POLYPODIACEAE	PTERIDIUM	2	.31%	0	1
SELAGINELLACEAE	SELAGINELLA	2	.31%	0	1
MISCEL	INDETER.	5	.79%	0	1
MISCEL	UNKNOWN	3	.47%	0	1
MISCEL	INDET BIS	31	4.93%	3	6

FILE: O'HARA

19 PRINCIPAL OF 30 IDENTIFIED TAXA

SAMPLE: 9 - DEPTH: 045CM - DEPOSITION RATE: .0139 CM/YR - CONTAMINANT: 24980#

COMMENT: BASE OF BRIDGE RIVER TEPHRA

FAMILY	PRINCIPAL TAXA	COUNT	FREQ.	95%	CI	CONC.	INF.
PINACEAE	PINUS HAPL	8	1.16%	0	2	3276	46
PINACEAE	PINUS DIPL	43	6.26%	4	8	17609	245.2
PINACEAE	PINUS	364	53.06%	49	56	149061	2072.4
PINACEAE	ABIES	37	5.39%	3	7	15152	211.1
PINACEAE	PICEA	120	17.49%	14	20	49141	683.5
PINACEAE	LARIX/PSEU	1	.14%	0	0	410	6.1
PINACEAE	TSUGA	6	.87%	0	1	2457	34.6
RANUNCULACEAE	THALICTRUM	2	.29%	0	1	819	11.8
BETULACEAE	ALNUS	80	11.66%	9	14	32761	455.8
BETULACEAE	BETULA	4	.58%	0	1	1638	23.2
GRAMINEAE	GRAMINEAE	7	1.02%	0	2	2867	40.3
CYPERACEAE	CYPERACEAE	1	.14%	0	0	410	6.1
COMPOSITAE	ARTEMISIA	2	.29%	0	1	819	11.8
COMPOSITAE	AMBROSIA	2	.29%	0	1	819	11.8
CHENO-AM	CHENO-AM	3	.43%	0	1	1229	17.5
CORNACEAE	CORNUS CAN	2	.29%	0	1	819	11.8
LORANTHACEAE	ARCEUTHOBIMUM	1	.14%	0	0	410	6.1
VALERIANACEAE	VALERIANA	2	.29%	0	1	819	11.8
ERICALES	ERICALES	1	.14%	0	0	410	6.1

SUM

686#

CONTAM. COUNT: 61#

CONCENTRATION: 280923#/CM3

INFLUX: 3905#/CM2/YR

FAMILY	EXCLUDED TAXA	COUNT	FREQ.	95%	CI
MISCEL	MONOLETE SPO	1	.14%	0	0
MISCEL	TRILETE SPO	2	.29%	0	1
MISCEL	INAPERTURATE	1	.14%	0	0
LYCOPODIACEAE	LYCOPODIUM	6	.87%	0	1
POLYPODIACEAE	DRYOPTERIS	3	.43%	0	1
POLYPODIACEAE	ATHYRIUM	5	.72%	0	1
POLYPODIACEAE	PTERIDIUM	2	.29%	0	1
SELAGINELLACEAE	SELAGINELLA	4	.58%	0	1
MISCEL	INDETER.	4	.58%	0	1
MISCEL	UNKNOWN	2	.29%	0	1
MISCEL	INDET BIS	40	5.83%	4	7

FILE: O'HARA

18 PRINCIPAL OF 27 IDENTIFIED TAXA

SAMPLE: 8 - DEPTH: 040CM - DEPOSITION RATE: .0179 CM/YR - CONTAMINANT: 24980#

COMMENT: ABOVE BRIDGE RIVER TEPHRA

FAMILY	PRINCIPAL TAXA	COUNT	FREQ.	95%	CI	CONC.	INF.
PINACEAE	PINUS HAPL	7	1.03%	0	2	3801	68.5
PINACEAE	PINUS DIPL	70	10.38%	8	12	38013	680.9
PINACEAE	PINUS	346	51.33%	47	55	187893	3363.7
PINACEAE	ABIES	32	4.74%	3	6	17377	311.5
PINACEAE	PICEA	113	16.76%	14	19	61364	1098.9
PINACEAE	LARIX/PSEU	1	.14%	0	0	543	10.2
PINACEAE	TSUGA	11	1.63%	0	2	5973	107.4
RANUNCULACEAE	THALICTRUM	1	.14%	0	0	543	10.2
BETULACEAE	ALNUS	73	10.83%	8	13	39642	710
BETULACEAE	BETULA	6	.89%	0	1	3258	58.8
SALICACEAE	SALIX	2	.29%	0	1	1086	19.9
GRAMINEAE	GRAMINEAE	1	.14%	0	0	543	10.2
CYPERACEAE	CYPERACEAE	2	.29%	0	1	1086	19.9
COMPOSITAE	ARTEMISIA	3	.44%	0	1	1629	29.6
COMPOSITAE	AMBROSIA	1	.14%	0	0	543	10.2
CHENO-AM	CHENO-AM	1	.14%	0	0	543	10.2
CORNACEAE	CORNUS CAN	2	.29%	0	1	1086	19.9
LORANTHACEAE	ARCEUTHOBium	2	.29%	0	1	1086	19.9

SUM 674#

CONTAM. COUNT: 46#

CONCENTRATION: 386011#/CM3

INFLUX: 6552#/CM2/YR

FAMILY	EXCLUDED TAXA	COUNT	FREQ.	95%	CI
MISCEL	TRILETE SPO	2	.29%	0	1
MISCEL	MONOLETE SPO	1	.14%	0	0
LYCOPODIACEAE	LYCOPodium	1	.14%	0	0
POLYPODIACEAE	DRYOPTERIS	5	.74%	0	1
POLYPODIACEAE	ATHYRIUM	1	.14%	0	0
POLYPODIACEAE	PTERIDIUM	3	.44%	0	1
MISCEL	INDETER.	8	1.18%	0	2
MISCEL	UNKNOWN	3	.44%	0	1
MISCEL	INDET BIS	38	5.63%	4	7

FILE: O'HARA

19 PRINCIPAL OF 29 IDENTIFIED TAXA

SAMPLE: 7 - DEPTH: 035CM - DEPOSITION RATE: .0179 CM/YR - CONTAMINANT: 24980#

COMMENT: NONE

FAMILY	PRINCIPAL TAXA	COUNT	FREQ.	95%	CI	CONC.	INF.
PINACEAE	PINUS HAPL	6	.8%	0	1	4684	84.3
PINACEAE	PINUS DIPL	58	7.77%	6	9	45276	810.9
PINACEAE	PINUS	406	54.42%	50	57	316934	5673.6
PINACEAE	ABIES	43	5.76%	4	7	33567	601.3
PINACEAE	PICEA	95	12.73%	10	15	74159	1327.9
PINACEAE	TSUGA	7	.93%	0	1	5464	98.3
POLYGONACEAE	OXYRIA	4	.53%	0	1	3123	56.4
RANUNCULACEAE	THALICTRUM	6	.8%	0	1	4684	84.3
BETULACEAE	ALNUS	96	12.86%	10	15	74940	1341.9
BETULACEAE	BETULA	4	.53%	0	1	3123	56.4
BETULACEAE	CORYLUS	1	.13%	0	0	781	14.4
GRAMINEAE	GRAMINEAE	7	.93%	0	1	5464	98.3
CYPERACEAE	CYPERACEAE	2	.26%	0	0	1561	28.4
COMPOSITAE	ARTEMISIA	6	.8%	0	1	4684	84.3
COMPOSITAE	AMBROSIA	1	.13%	0	0	781	14.4
CORNACEAE	CORNUS CAN	1	.13%	0	0	781	14.4
LORANTHACEAE	ARCEUTHOBIMUM	1	.13%	0	0	781	14.4
CARYOPHYLLACEAE	CARYOPHYLLACEAE	1	.13%	0	0	781	14.4
ERICALES	ERICALES	1	.13%	0	0	781	14.4

SUM 746#

CONTAM. COUNT: 32#

CONCENTRATION: 582346#/CM3

INFLUX: 10424#/CM2/YR

FAMILY	EXCLUDED TAXA	COUNT	FREQ.	95%	CI
MISCEL	TRILETE SPO	2	.26%	0	0
MISCEL	MONOLETE SPO	2	.26%	0	0
LYCOPODIACEAE	LYCOPODIUM	1	.13%	0	0
POLYPODIACEAE	DRYOPTERIS	8	1.07%	0	2
POLYPODIACEAE	PTERIDIUM	1	.13%	0	0
POLYPODIACEAE	ATHYRIUM	2	.26%	0	0
SELAGINELLACEAE	SELAGINELLA	2	.26%	0	0
MISCEL	INDETER.	8	1.07%	0	2
MISCEL	UNKNOWN	2	.26%	0	0
MISCEL	INDET BIS	37	4.95%	3	6

FILE: O'HARA

19 PRINCIPAL OF 27 IDENTIFIED TAXA

SAMPLE: 6 - DEPTH: 030CM - DEPOSITION RATE: .0179 CM/YR - CONTAMINANT: 24980#

COMMENT: NONE

FAMILY	PRINCIPAL TAXA	COUNT	FREQ.	95%	CI	CONC.	INF.
PINACEAE	PINUS HAPL	15	2.3%	1	3	11021	197.7
PINACEAE	PINUS DIPL	45	6.91%	5	9	33062	592.3
PINACEAE	PINUS	359	55.14%	51	58	263759	4721.7
PINACEAE	ABIES	30	4.6%	3	6	22041	395
PINACEAE	PICEA	118	18.12%	15	21	86695	1552.3
PINACEAE	LARIX/PSEU	2	.3%	0	1	1469	26.7
PINACEAE	TSUGA	12	1.84%	1	3	8816	158.3
POLYGONACEAE	OXYRIA	2	.3%	0	1	1469	26.7
RANUNCULACEAE	THALICTRUM	1	.15%	0	0	735	13.6
ROSACEAE	POTENTILLA	1	.15%	0	0	735	13.6
BETULACEAE	ALNUS	51	7.83%	6	10	37470	671.2
BETULACEAE	BETULA	3	.46%	0	1	2204	39.9
SALICACEAE	SALIX	1	.15%	0	0	735	13.6
GRAMINEAE	GRAMINEAE	3	.46%	0	1	2204	39.9
CYPERACEAE	CYPERACEAE	1	.15%	0	0	735	13.6
COMPOSITAE	ARTIMESIA	3	.46%	0	1	2204	39.9
CHENO-AM	CHENO-AM	2	.3%	0	1	1469	26.7
ELAEAGNACEAE	SHEPHERDIA CAN	1	.15%	0	0	735	13.6
CARYOPHYLLACEAE	CARYOPHYLLACEAE	1	.15%	0	0	735	13.6

SUM 651#

CONTAM. COUNT: 34#

CONCENTRATION: 478294#/CM3

INFLUX: 8561#/CM2/YR

FAMILY	EXCLUDED TAXA	COUNT	FREQ.	95%	CI
MISCEL	MONOLETE SPO	1	.15%	0	0
MISCEL	TRILETE SPO	1	.15%	0	0
POLYPODIACEAE	DRYOPTERIS	6	.92%	0	1
POLYPODIACEAE	PTERIDIUM	1	.15%	0	0
SELAGINELLACEAE	SELAGINELLA	1	.15%	0	0
MISCEL	INDETER.	6	.92%	0	1
MISCEL	UNKNOWN	4	.61%	0	1
MISCEL	INDET BIS	57	8.75%	6	11

FILE: O'HARA

17 PRINCIPAL OF 28 IDENTIFIED TAXA

SAMPLE: 5 - DEPTH: 025CM - DEPOSITION RATE: .0179 CM/YR - CONTAMINANT: 24980#

COMMENT: NONE

FAMILY	PRINCIPAL TAXA	COUNT	FREQ.	95%	CI	CONC.	INF.
PINACEAE	PINUS HAPL	20	2.46%	1	3	11102	199.2
PINACEAE	PINUS DIPL	38	7.16%	5	9	32196	576.8
PINACEAE	PINUS	462	57.03%	53	60	256461	4591.1
PINACEAE	ABIES	38	4.69%	3	6	21094	378
PINACEAE	PICEA	125	15.43%	13	18	69389	1242.5
PINACEAE	LARIX/PSEU	2	.24%	0	0	1110	20.3
PINACEAE	TSUGA	14	1.72%	1	2	7772	139.6
POLYGONACEAE	OXYRIA	2	.24%	0	0	1110	20.3
RANUNCULACEAE	THALICTRUM	1	.12%	0	0	555	10.4
ROSACEAE	POTENTILLA	1	.12%	0	0	555	10.4
BETULACEAE	ALNUS	71	8.76%	7	10	39413	705.9
BETULACEAE	BETULA	2	.24%	0	0	1110	20.3
GRAMINEAE	GRAMINEAE	3	.37%	0	1	1665	30.3
CYPERACEAE	CYPERACEAE	3	.37%	0	1	1665	30.3
COMPOSITAE	ARTEMISIA	5	.61%	0	1	2776	50.1
LORANTHACEAE	ARCEUTHOBIMUM	1	.12%	0	0	555	10.4
ERICALES	ERICALES	2	.24%	0	0	1110	20.3

SUM

810#

CONTAM. COUNT: 45#

CONCENTRATION: 449640#/CM3

INFLUX: 8049#/CM2/YR

FAMILY	EXCLUDED TAXA	COUNT	FREQ.	95%	CI
EQUISETACEAE	EQUISETUM	1	.12%	0	0
MISCEL	TRILETE SPO	2	.24%	0	0
MISCEL	MONOLETE SPO	1	.12%	0	0
MISCEL	INAPERTURATE SPO	1	.12%	0	0
LYCOPODIACEAE	LYCOPodium	4	.49%	0	1
POLYPODIACEAE	DRYOPTERIS	3	.37%	0	1
POLYPODIACEAE	ATHYRIUM	1	.12%	0	0
POLYPODIACEAE	PTERIDIUM	1	.12%	0	0
MISCEL	INDETER.	9	1.11%	0	2
MISCEL	UNKNOWN	2	.24%	0	0
MISCEL	INDET BIS	46	5.67%	4	7

FILE: O'HARA

21 PRINCIPAL OF 30 IDENTIFIED TAXA

SAMPLE: 4 - DEPTH: 020CM - DEPOSITION RATE: .0179 CM/YR - CONTAMINANT: 24980#

COMMENT: NONE

FAMILY	PRINCIPAL TAXA	COUNT	FREQ.	95%	CI	CONC.	INF.
PINACEAE	PINUS HAPL	13	1.77%	1	3	9021	161.9
PINACEAE	PINUS DIPL	45	6.13%	4	8	31225	559.4
PINACEAE	PINUS	453	61.71%	58	65	314332	5627
PINACEAE	ABIES	28	3.81%	2	5	19429	348.2
PINACEAE	PICEA	85	11.58%	9	14	58981	1056.2
PINACEAE	LARIX/PSEU	2	.27%	0	0	1388	25.3
PINACEAE	TSUGA	17	2.31%	1	3	11796	211.6
POLYGONACEAE	OXYRIA	1	.13%	0	0	694	12.9
POLYGONACEAE	ERIGONUM	1	.13%	0	0	694	12.9
RANUNCULACEAE	THALICTRUM	1	.13%	0	0	694	12.9
BETULACEAE	ALNUS	57	7.76%	6	9	39552	708.4
BETULACEAE	BETULA	4	.54%	0	1	2776	50.1
SALICACEAE	SALIX	3	.4%	0	1	2082	37.7
GRAMINEAE	GRAMINEAE	6	.81%	0	1	4163	75
CYPERACEAE	CYPERACEAE	5	.68%	0	1	3469	62.5
COMPOSITAE	ARTEMISIA	4	.54%	0	1	2776	50.1
COMPOSITAE	AMBROSIA	1	.13%	0	0	694	12.9
COMPOSITAE	TUBULIFL H.S.	3	.4%	0	1	2082	37.7
CHENO-AM	CHENO-AM	2	.27%	0	0	1388	25.3
ERICALES	ERICALES	2	.27%	0	0	1388	25.3
LEGUMINOSAE	ASTRAGALUS	1	.13%	0	0	694	12.9

SUM

734#

CONTAM. COUNT: 36#

CONCENTRATION: 509314#/CM3

INFLUX: 9117#/CM2/YR

FAMILY	EXCLUDED TAXA	COUNT	FREQ.	95%	CI
MISCEL	MONOLETE SPO	4	.54%	0	1
MISCEL	TRILETE SPO	3	.4%	0	1
LYCOPODIACEAE	LYCOPODIUM	2	.27%	0	0
POLYPODIACEAE	DRYOPTERIS	6	.81%	0	1
POLYPODIACEAE	PTERIDIUM	2	.27%	0	0
SELAGINELLACEAE	SELAGINELLA	1	.13%	0	0
MISCEL	INDETER.	6	.81%	0	1
MISCEL	UNKNOWN	3	.4%	0	1
MISCEL	INDET BIS	37	5.04%	3	6

FILE: O'HARA

13 PRINCIPAL OF 21 IDENTIFIED TAXA

SAMPLE: 3 - DEPTH: 015CM - DEPOSITION RATE: .0179 CM/YR - CONTAMINANT: 24980#

COMMENT: NONE

FAMILY	PRINCIPAL TAXA	COUNT	FREQ.	95%	CI	CONC.	INF.
PINACEAE	PINUS HAPL	10	1.45%	0	2	5430	97.6
PINACEAE	PINUS DIPL	30	4.35%	3	6	16291	292.1
PINACEAE	PINUS	439	63.71%	60	67	238396	4267.7
PINACEAE	ABIES	32	4.64%	3	6	17377	311.5
PINACEAE	PICEA	93	13.49%	11	16	50503	904.5
PINACEAE	TSUGA	13	1.88%	1	3	7060	126.8
POLYGONACEAE	OXYRIA	1	.14%	0	0	543	10.2
BETULACEAE	ALNUS	49	7.11%	5	9	26609	476.8
BETULACEAE	BETULA	6	.87%	0	1	3258	58.8
GRAMINEAE	GRAMINEAE	6	.87%	0	1	3258	58.8
CYPERACEAE	CYPERACEAE	3	.43%	0	1	1629	29.6
COMPOSITAE	ARTEMISIA	2	.29%	0	1	1086	19.9
CHENO-AM	CHENO-AM	5	.72%	0	1	2715	49

SUM 689#

CONTAM. COUNT: 46#

CONCENTRATION: 374157#/CM3

INFLUX: 6697#/CM2/YR

FAMILY	EXCLUDED TAXA	COUNT	FREQ.	95%	CI
MISCEL	MONOLETE SPO	2	.29%	0	1
MISCEL	TRILETE SPO	1	.14%	0	0
LYCOPODIACEAE	LYCOPODIUM	1	.14%	0	0
POLYPODIACEAE	PTERIDIUM	1	.14%	0	0
POLYPODIACEAE	DRYOPTERIS	4	.58%	0	1
MISCEL	INDETER.	8	1.16%	0	2
MISCEL	UNKNOWN	2	.29%	0	1
MISCEL	INDET BIS	35	5.07%	3	6

FILE: O'HARA

18 PRINCIPAL OF 25 IDENTIFIED TAXA

SAMPLE: 2 - DEPTH: 010CM - DEPOSITION RATE: .0179 CM/YR - CONTAMINANT: 24980#

COMMENT: NONE

FAMILY	PRINCIPAL TAXA	COUNT	FREQ.	95%	CI	CONC.	INF.
PINACEAE	PINUS HAPL	11	1.45%	0	2	5725	102.9
PINACEAE	PINUS DIPL	42	5.56%	4	7	21858	391.7
PINACEAE	PINUS	410	54.3%	50	57	213371	3819.8
PINACEAE	ABIES	41	5.43%	4	7	21337	382.4
PINACEAE	PICEA	88	11.65%	9	14	45797	820.2
PINACEAE	LARIX/PSEU	5	.66%	0	1	2602	47
PINACEAE	TSUGA	14	1.85%	1	3	7286	130.9
POLYGONACEAE	OXYRIA	3	.39%	0	1	1561	28.4
BETULACEAE	ALNUS	101	13.37%	11	15	52562	941.3
BETULACEAE	BETULA	5	.66%	0	1	2602	47
SALICACEAE	SALIX	4	.52%	0	1	2082	37.7
GRAMINEAE	GRAMINEAE	11	1.45%	0	2	5725	102.9
CYPERACEAE	CYPERACEAE	2	.26%	0	0	1041	19.7
COMPOSITAE	ARTEMISIA	8	1.05%	0	2	4163	75
COMPOSITAE	TUBULIFL H.S.	5	.66%	0	1	2602	47
COMPOSITAE	AMBROSIA	1	.13%	0	0	520	9.8
CHENO-AM	CHENO-AM	3	.39%	0	1	1561	28.4
ERICALES	ERICALES	1	.13%	0	0	520	9.8
SUM		755#					

CONTAM. COUNT: 48#

CONCENTRATION: 392915#/CM3

INFLUX: 7033#/CM2/YR

FAMILY	EXCLUDED TAXA	COUNT	FREQ.	95%	CI
MISCEL	MONOLETE SPO	5	.66%	0	1
MISCEL	TRILETE SPO	2	.26%	0	0
POLYPODIACEAE	DRYOPTERIS	4	.52%	0	1
SELAGINELLACEAE	SELAGINELLA	3	.39%	0	1
MISCEL	INDETER.	13	1.72%	1	2
MISCEL	UNKNOWN	4	.52%	0	1
MISCEL	INDET BIS	43	5.69%	4	7

FILE: O'HARA

17 PRINCIPAL OF 27 IDENTIFIED TAXA

SAMPLE: 1 - DEPTH: 005CM - DEPOSITION RATE: .0179 CM/YR - CONTAMINANT: 24980#

COMMENT: NONE

FAMILY	PRINCIPAL TAXA	COUNT	FREQ.	95%	CI	CONC.	INF.
PINACEAE	PINUS HAPL	13	1.86%	1	3	5074	91.3
PINACEAE	PINUS DIPL	46	6.6%	4	8	17954	321.8
PINACEAE	PINUS	420	60.34%	56	63	163931	2934.8
PINACEAE	ABIES	32	4.59%	3	6	12490	224
PINACEAE	PICEA	73	10.48%	8	12	28493	510.5
PINACEAE	TSUGA	10	1.43%	0	2	3903	70.3
POLYGONACEAE	OXYRIA	3	.43%	0	1	1171	21.4
BETULACEAE	ALNUS	68	9.77%	7	12	26541	475.5
BETULACEAE	BETULA	5	.71%	0	1	1952	35.4
SALICACEAE	SALIX	3	.43%	0	1	1171	21.4
GRAMINEAE	GRAMINEAE	4	.57%	0	1	1561	28.4
CYPERACEAE	CYPERACEAE	3	.43%	0	1	1171	21.4
COMPOSITAE	ARTEMISIA	9	1.29%	0	2	3513	63.3
COMPOSITAE	TUBULIFL H.S.	1	.14%	0	0	390	7.4
CHENO-AM	CHENO-AM	3	.43%	0	1	1171	21.4
UMBELLIFERAE	HERACLEUM	1	.14%	0	0	390	7.4
ERICALES	ERICALES	2	.28%	0	1	781	14.4

SUM

696#

CONTAM. COUNT: 64#

CONCENTRATION: 271658#/CM3

INFLUX: 4863#/CM2/YR

FAMILY	EXCLUDED TAXA	COUNT	FREQ.	95%	CI
MISCEL	TRILETE SPO	3	.43%	0	1
MISCEL	MONOLETE SPO	2	.28%	0	1
MISCEL	INAPERTURATE SPO	1	.14%	0	0
LYCOPODIACEAE	LYCOPODIUM	1	.14%	0	0
POLYPODIACEAE	DRYOPTERIS	7	1.0%	0	2
POLYPODIACEAE	ATHYRIUM	3	.43%	0	1
POLYPODIACEAE	PTERIDIUM	1	.14%	0	0
MISCEL	INDETER.	7	1.0%	0	2
MISCEL	UNKNOWN	3	.43%	0	1
MISCEL	INDET BIS	46	6.6%	4	8

FILE: OPABIN

18 PRINCIPAL OF 25 IDENTIFIED TAXA

SAMPLE: 22 - DEPTH: 110CM - DEPOSITION RATE: 0 CM/YR - CONTAMINANT: 24154#

COMMENT: BASE OF CORE

FAMILY	PRINCIPAL TAXA	COUNT	FREQ.	95%	CI	CONC.	INF.
PINACEAE	PINUS HAPL	4	1.63%	0	4	366	.5
PINACEAE	PINUS DIPL	6	2.45%	1	5	549	.5
PINACEAE	PINUS	102	41.8%	35	48	9332	.5
PINACEAE	PICEA	5	2.04%	0	4	457	.5
PINACEAE	ABIES	5	2.04%	0	4	457	.5
RANUNCULACEAE	THALICTRUM	1	.4%	0	2	91	.5
RANUNCULACEAE	DELPHINIUM	1	.4%	0	2	91	.5
ROSACEAE	DRYAS	1	.4%	0	2	91	.5
BETULACEAE	ALNUS	43	17.62%	13	22	3934	.5
SALICACEAE	SALIX	6	2.45%	1	5	549	.5
GRAMINEAE	GRAMINEAE	10	4.09%	2	7	915	.5
CYPERACEAE	CYPERACEAE	2	.81%	0	2	183	.5
COMPOSITAE	ARTEMISIA	51	20.9%	16	26	4666	.5
COMPOSITAE	TUBULIFL H.S.	2	.81%	0	2	183	.5
CHENO-AM	CHENO-AM	2	.81%	0	2	183	.5
CHENO-AM	SARCOBATUS	1	.4%	0	2	91	.5
PLANTAGINACEAE	PLANTAGO	1	.4%	0	2	91	.5
PRIMULACEAE	ANDROSACE	1	.4%	0	2	91	.5

SUM 244#

CONTAM. COUNT: 264 #

CONCENTRATION: 22324#/CM3

FAMILY	EXCLUDED TAXA	COUNT	FREQ.	95%	CI
MISCEL	MONOLETE SPO	1	.4%	0	2
MISCEL	TRILETE SPO	3	1.22%	0	3
SELAGINELLACEAE	SELAGINELLA	1	.4%	0	2
POLYPODIACEAE	PTERIDIUM	1	.4%	0	2
MISCEL	INDETER.	13	5.32%	3	8
MISCEL	INDET BIS	14	5.73%	3	9
MISCEL	UNKNOWN	2	.81%	0	2

FILE: OPABIN

18 PRINCIPAL OF 24 IDENTIFIED TAXA

SAMPLE: 21 - DEPTH: 105CM - DEPOSITION RATE: 0 CM/YR - CONTAMINANT: 24154#

COMMENT: NONE

FAMILY	PRINCIPAL TAXA	COUNT	FREQ.	95%	CI	CONC.	INF.
PINACEAE	PINUS HAPL	5	2.23%	0	5	412	.5
PINACEAE	PINUS DIPL	7	3.12%	1	6	577	.5
PINACEAE	PINUS	65	29.01%	23	35	5358	.5
PINACEAE	PICEA	4	1.78%	0	4	330	.5
PINACEAE	ABIES	2	.89%	0	3	165	.5
RANUNCULACEAE	THALICTRUM	5	2.23%	0	5	412	.5
RANUNCULACEAE	RANUNCULUS	2	.89%	0	3	165	.5
RANUNCULACEAE	DELPHINIUM	1	.44%	0	2	82	.5
ROSACEAE	FRAGARIA	1	.44%	0	2	82	.5
BETULACEAE	ALNUS	22	9.82%	6	14	1814	.5
BETULACEAE	CORYLUS	1	.44%	0	2	82	.5
SALICACEAE	SALIX	17	7.58%	4	11	1401	.5
GRAMINEAE	GRAMINEAE	5	2.23%	0	5	412	.5
CYPERACEAE	CYPERACEAE	2	.89%	0	3	165	.5
COMPOSITAE	ARTEMISIA	72	32.14%	26	38	5935	.5
COMPOSITAE	TUBULIFL H.S.	6	2.67%	1	5	495	.5
CHENO-AM	CHENO-AM	6	2.67%	1	5	495	.5
CHENO-AM	SARCOBATUS	1	.44%	0	2	82	.5

SUM

224#

CONTAM. COUNT: 293#

CONCENTRATION: 18466#/CM3

INFLUX: 0#/CM2/YR

FAMILY	EXCLUDED TAXA	COUNT	FREQ.	95%	CI
MISCEL	INAPERTURATE SPO	2	.89%	0	3
MISCEL	TRILETE SPO	5	2.23%	0	5
SELAGINELLACEAE	SELAGINELLA	2	.89%	0	3
MISCEL	INDETER.	17	7.58%	4	11
MISCEL	UNKNOWN	5	2.23%	0	5
MISCEL	INDET BIS	4	1.78%	0	4

FILE: OPABIN

17 PRINCIPAL OF 22 IDENTIFIED TAXA

SAMPLE: 20 - DEPTH: 100CM - DEPOSITION RATE: 0 CM/YR - CONTAMINANT: 24154#

COMMENT: BELOW BASAL CONTACT

FAMILY	PRINCIPAL TAXA	COUNT	FREQ.	95%	CI	CONC.	INF.
PINACEAE	PINUS HAPL	8	2.95%	1	5	199	.5
PINACEAE	PINUS DIPL	9	3.32%	1	6	2 41	.5
PINACEAE	PINUS	142	52.39%	46	58	35359	.5
PINACEAE	PICEA	1	.36%	0	2	249	.5
PINACEAE	ABIES	2	.73%	0	2	498	.5
RANUNCULACEAE	RANUNCULUS	1	.36%	0	2	249	.5
SAXIFRAGACEAE	SAXIFRAGA	1	.36%	0	2	249	.5
BETULACEAE	BETULA	1	.36%	0	2	249	.5
BETULACEAE	ALNUS	15	5.53%	3	8	3735	.5
SALICACEAE	SALIX	7	2.58%	1	5	1743	.5
GRAMINEAE	GRAMINEAE	8	2.95%	1	5	1992	.5
CYPERACEAE	CYPERACEAE	3	1.1%	0	3	747	.5
COMPOSITAE	ARTEMISIA	66	24.35%	19	29	16435	.5
COMPOSITAE	TUBULIFL L.S.	1	.36%	0	2	249	.5
COMPOSITAE	TUBULIFL H.S.	1	.36%	0	2	249	.5
CHENO-AM	SARCOBATUS	1	.36%	0	2	249	.5
CHENO-AM	CHENO-AM	4	1.47%	0	3	996	.5

SUM

271#

CONTAM. COUNT: 97 #

CONCENTRATION: 67482#/CM3

INFLUX: 0#/CM2/YR

FAMILY	EXCLUDED TAXA	COUNT	FREQ.	95%	CI
MISCEL	TRILETE SPO	2	.73%	0	2
SELAGINELLACEAE	SELAGINELLA	2	.73%	0	2
MISCEL	INDETER.	16	5.9%	3	9
MISCEL	UNKNOWN	9	3.32%	1	6
MISCEL	INDET BIS	5	1.84%	0	4

FILE: OPABIN

14 PRINCIPAL OF 23 IDENTIFIED TAXA

SAMPLE: 19 - DEPTH: 095CM - DEPOSITION RATE: 3.5E-03 CM/YR - CONTAMINANT: 24154#

COMMENT: ABOVE BASAL CONTACT

FAMILY	PRINCIPAL TAXA	COUNT	FREQ.	95%	CI	CONC.	INF.
PINACEAE	PINUS HAPL	20	3.78%	2	5	20128	70.9
PINACEAE	PINUS DIPL	12	2.27%	1	3	12077	42.7
PINACEAE	PINUS	363	68.75%	64	72	365329	1279.1
PINACEAE	PICEA	7	1.32%	0	2	7045	25.1
PINACEAE	ABIES	14	2.65%	1	4	14090	49.8
SAXIFRAGACEAE	SAXIFRAGA	1	.18%	0	1	1006	4
CUPRESSACEAE	JUNIPERUS	12	2.27%	1	3	12077	42.7
BETULACEAE	BETULA	2	.37%	0	1	2013	7.5
BETULACEAE	ALNUS	80	15.15%	12	18	80513	282.2
SALICACEAE	SALIX	1	.18%	0	1	1006	4
GRAMINEAE	GRAMINEAE	4	.75%	0	1	4026	14.5
CYPERACEAE	CYPERACEAE	2	.37%	0	1	2013	7.5
COMPOSITAE	ARTEMISIA	9	1.7%	0	3	9058	32.2
CORNACEAE	CORNUS CAN	1	.18%	0	1	1006	4

SUM

528#

CONTAM. COUNT: 24 #

CONCENTRATION: 531388#/CM3

INFLUX: 1860#/CM2/YR

FAMILY	EXCLUDED TAXA	COUNT	FREQ.	95%	CI
MISCEL	TRILETE SPO	4	.75%	0	1
MISCEL	MONOLETE SPO	2	.37%	0	1
MISCEL	INAPERTURATE SPO	1	.18%	0	1
POLYPODIACEAE	DRYOPTERIS	6	1.13%	0	2
LYCOPODIACEAE	LYCOPODIUM	2	.37%	0	1
POLYPODIACEAE	PTERIDIUM	1	.18%	0	1
MISCEL	INDETER.	22	4.16%	2	6
MISCEL	UNKNOWN	4	.75%	0	1
MISCEL	INDET BIS	28	5.3%	3	7

FILE: OPABIN

16 PRINCIPAL OF 27 IDENTIFIED TAXA

SAMPLE: 18 - DEPTH: 090CM - DEPOSITION RATE: 3.5E-03 CM/YR - CONTAMINANT: 24154#

COMMENT: NONE

FAMILY	PRINCIPAL TAXA	COUNT	FREQ.	95%	CI	CONC.	INF.
PINACEAE	PINUS HAPL	18	3.54%	2	5	15528	54.8
PINACEAE	PINUS DIPL	10	1.96%	1	3	8626	30.6
PINACEAE	PINUS	295	58.07%	53	62	254480	891.1
PINACEAE	PICEA	6	1.18%	0	2	15176	18.6
PINACEAE	ABIES	20	3.93%	2	6	17253	60.8
PINACEAE	LARIX/PSEU	2	.39%	0	1	1725	6.5
ROSACEAE	DRYAS	2	.39%	0	1	1725	6.5
CUPRESSACEAE	JUNIPERUS	3	.59%	0	1	2588	9.5
BETULACEAE	BETULA	4	.78%	0	2	3451	12.5
BETULACEAE	ALNUS	117	23.03%	19	26	100929	353.7
FAGACEAE	QUERCUS	1	.19%	0	1	863	3.5
GRAMINEAE	GRAMINEAE	3	.59%	0	1	2588	9.5
CYPERACEAE	CYPERACEAE	4	.78%	0	2	3451	12.5
COMPOSITAE	ARTEMISIA	21	4.13%	2	6	18116	63.9
COMPOSITAE	AMBROSIA	1	.19%	0	1	863	3.5
CHENO-AM	CHENO-AM	1	.19%	0	1	863	3.5

SUM 508#

CONTAM. COUNT: 28 #

CONCENTRATION: 438223#/CM3

INFLUX: 1534#/CM2/YR

FAMILY	EXCLUDED TAXA	COUNT	FREQ.	95%	CI
MISCEL	TRILETE SPO	6	1.18%	0	2
MISCEL	MONOLETE SPO	1	.19%	0	1
MISCEL	INAPERTURATE SPO	2	.39%	0	1
POLYPODIACEAE	DRYOPTERIS	4	.78%	0	2
POLYPODIACEAE	ATHYRIUM	1	.19%	0	1
POLYPODIACEAE	PTERIDIUM	3	.59%	0	1
LYCOPODIACEAE	LYCOPODIUM	1	.19%	0	1
SELAGINELLACEAE	SELAGINELLA	1	.19%	0	1
MISCEL	INDETER.	13	2.55%	1	4
MISCEL	INDET BIS	38	7.48%	5	10
MISCEL	UNKNOWN	5	.98%	0	2

FILE: OPABIN

22 PRINCIPAL OF 32 IDENTIFIED TAXA

SAMPLE: 17 - DEPTH: 085CM - DEPOSITION RATE: 3.5E-03 CM/YR - CONTAMINANT: 24154#

COMMENT: BELOW MAZAMA TEPHRA

FAMILY	PRINCIPAL TAXA	COUNT	FREQ.	95%	CI	CONC.	INF.
PINACEAE	PINUS	206	32.9%	29	36	87293	306
PINACEAE	PINUS HAPL	27	4.31%	2	6	11441	40.5
PINACEAE	PINUS DIPL	16	2.55%	1	4	6780	24.2
PINACEAE	PICEA	39	6.23%	4	8	16526	58.3
PINACEAE	ABIES	53	8.46%	6	10	22459	79.1
PINACEAE	LARIX/PSEU	2	.31%	0	1	848	3.4
RANUNCULACEAE	THALICTRUM	12	1.91%	1	3	5085	18.2
ROSACEAE	POTENTILLA	1	.15%	0	0	424	1.9
BETULACEAE	BETULA	9	1.43%	0	2	3814	13.8
BETULACEAE	ALNUS	181	28.91%	25	32	76700	268.9
SALICACEAE	SALIX	5	.79%	0	1	2119	7.9
GRAMINEAE	GRAMINEAE	14	2.23%	1	3	5933	21.2
CYPERACEAE	CYPERACEAE	8	1.27%	0	2	3390	12.3
COMPOSITAE	ARTEMISIA	32	5.11%	3	7	13560	47.9
COMPOSITAE	TUBULIFL H.S.	5	.79%	0	1	2119	7.9
COMPOSITAE	AMBROSIA	1	.15%	0	0	424	1.9
CHENO-AM	CHENO-AM	10	1.59%	0	2	4238	15.3
CHENO-AM	SARCOBATUS	1	.15%	0	0	424	1.9
CORNACEAE	CORNUS CAN	1	.15%	0	0	424	1.9
LORANTHACEAE	ARCEUTHOBium	1	.15%	0	0	424	1.9
CRASSULACEAE	SEDUM	1	.15%	0	0	424	1.9
VALERIANACEAE	VALERIANA	1	.15%	0	0	424	1.9

SUM

626#

CONTAM. COUNT: 57 #

CONCENTRATION: 265270#/CM3

INFLUX: 928#/CM2/YR

FAMILY	EXCLUDED TAXA	COUNT	FREQ.	95%	CI
MISCEL	TRILETE SPO	3	.47%	0	1
MISCEL	MONOLETE SPO	5	.79%	0	1
MISCEL	INAPERTURATE SPO	4	.63%	0	1
POLYPODIACEAE	DRYOPTERIS	8	1.27%	0	2
POLYPODIACEAE	ATHYRIUM	3	.47%	0	1
POLYPODIACEAE	PTERIDIUM	8	1.27%	0	2
LYCOPODIACEAE	LYCOPodium	1	.15%	0	0
MISCEL	INDETER.	30	4.79%	3	6
MISCEL	UNKNOWN	6	.95%	0	2
MISCEL	INDET BIS	45	7.18%	5	9

FILE: OPABIN

21 PRINCIPAL OF 31 IDENTIFIED TAXA

SAMPLE: 16 - DEPTH: 080CM - DEPOSITION RATE: 8.5E-03 CM/YR - CONTAMINANT: 24154#

COMMENT: ABOVE MAZAMA TEPHRA

FAMILY	PRINCIPAL TAXA	COUNT	FREQ.	95%	CI	CONC.	INF.
PINACEAE	PINUS	226	32.89%	29	36	121307	1031.6
PINACEAE	PINUS HAPL	26	3.78%	2	5	13956	119.1
PINACEAE	PINUS DIPL	24	3.49%	2	5	12882	109.9
PINACEAE	PICEA	48	6.98%	5	9	25764	219.4
PINACEAE	ABIES	70	10.18%	8	12	37573	319.8
PINACEAE	LARIX/PSEU	3	.43%	0	1	1610	14.1
POLYGONACEAE	POLYGONACEAE	1	.14%	0	0	537	5
RANUNCULACEAE	THALICTRUM	4	.58%	0	1	2147	18.7
CUPRESSACEAE	JUNIPERUS	1	.14%	0	0	537	5
BETULACEAE	BETULA	5	.72%	0	1	2684	23.3
BETULACEAE	ALNUS	210	30.56%	27	34	112719	958.6
GRAMINEAE	GRAMINEAE	5	.72%	0	1	2684	23.3
CYPERACEAE	CYPERACEAE	12	1.74%	1	3	6441	55.2
COMPOSITAE	ARTEMISIA	30	4.36%	3	6	16103	137.3
COMPOSITAE	TUBULIFL H.S.	7	1.01%	0	2	3757	32.4
COMPOSITAE	AMBROSIA	1	.14%	0	0	537	5
CHENO-AM	CHENO-AM	9	1.31%	0	2	4831	41.5
CRASSULACEAE	SEDUM	1	.14%	0	0	537	5
CARYOPHYLLACEAE	CARYOPHYLLACEAE	1	.14%	0	0	537	5
VALERIANACEAE	VALERIANA	1	.14%	0	0	537	5
ERICALES	ERICALES	2	.29%	0	1	1074	9
SUM		687#					

CONTAM. COUNT: 45 #

CONCENTRATION: 368751#/CM3

INFLUX: 3134#/CM2/YR

FAMILY	EXCLUDED TAXA	COUNT	FREQ.	95%	CI
MISCEL	TRILETE SPO	1	.14%	0	0
MISCEL	MONOLETE SPO	1	.14%	0	0
POLYPODIACEAE	DRYOPTERIS	5	.72%	0	1
POLYPODIACEAE	ATHYRIUM	4	.58%	0	1
POLYPODIACEAE	PTERIDIUM	9	1.31%	0	2
LYCOPODIACEAE	LYCOPODIUM	1	.14%	0	0
SELAGINELLACEAE	SELAGINELLA	3	.43%	0	1
MISCEL	INDETER.	22	3.2%	2	4
MISCEL	INDET BIS	47	6.84%	5	8
MISCEL	UNKNOWN	8	1.16%	0	2

FILE: OPABIN

21 PRINCIPAL OF 30 IDENTIFIED TAXA

SAMPLE: 15 - DEPTH: 075CM - DEPOSITION RATE: 8.5E-03 CM/YR - CONTAMINANT: 24154#

COMMENT: NONE

FAMILY	PRINCIPAL TAXA	COUNT	FREQ.	95%	CI	CONC.	INF.
PINACEAE	PINUS	226	34.13%	30	37	124064	1055
PINACEAE	PINUS HAPL	26	3.92%	2	5	14273	121.8
PINACEAE	PINUS DIPL	24	3.62%	2	5	13175	112.4
PINACEAE	PICEA	47	7.09%	5	9	25801	219.8
PINACEAE	ABIES	65	9.81%	7	12	35682	303.7
PINACEAE	LARIX/PSEU	8	1.2%	0	2	4392	37.8
POLYGONACEAE	OXYRIA	1	.15%	0	0	549	5.1
RANUNCULACEAE	THALICTRUM	4	.6%	0	1	2196	19.1
SAXIFRAGACEAE	SAXIFRAGA	2	.3%	0	1	1098	9.8
ROSACEAE	POTENTILLA	1	.15%	0	0	549	5.1
CUPRESSACEAE	JUNIPERUS	3	.45%	0	1	1647	14.4
BETULACEAE	BETULA	5	.75%	0	1	2745	23.8
BETULACEAE	ALNUS	197	29.75%	26	33	108144	919.7
SALICACEAE	SALIX	1	.15%	0	0	549	5.1
GRAMINEAE	GRAMINEAE	9	1.35%	0	2	4941	42.4
CYPERACEAE	CYPERACEAE	7	1.05%	0	2	3843	38.1
COMPOSITAE	ARTEMISIA	23	3.47%	2	5	12626	107.8
COMPOSITAE	TUBULIFL H.S.	4	.6%	0	1	2196	19.1
CHENO-AM	CHENO-AM	7	1.05%	0	2	3843	33.1
LORANTHACEAE	ARCEUTHOBIMUM	1	.15%	0	0	549	5.1
ERICALES	ERICALES	1	.15%	0	0	549	5.1

SUM 662#

CONTAM. COUNT: 44 #

CONCENTRATION: 363408#/CM3

INFLUX: 3089#/CM2/YR

FAMILY	EXCLUDED TAXA	COUNT	FREQ.	95%	CI
MISCEL	MONOLETE SPO	2	.3%	0	1
MISCEL	TRILETE SPO	3	.45%	0	1
POLYPODIACEAE	DRYOPTERIS	5	.75%	0	1
POLYPODIACEAE	ATHYRIUM	1	.15%	0	0
POLYPODIACEAE	PTERIDIUM	4	.6%	0	1
LYCOPODIACEAE	LYCOPODIUM	3	.45%	0	1
MISCEL	INDETER.	16	2.41%	1	3
MISCEL	INDET BIS	42	6.34%	4	8
MISCEL	UNKNOWN	5	.75%	0	1

FILE: OPABIN

17 PRINCIPAL OF 26 IDENTIFIED TAXA

SAMPLE: 14 - DEPTH: 070CM - DEPOSITION RATE: 8.5E-03 CM/YR - CONTAMINANT: 24154#

COMMENT: NONE

FAMILY	PRINCIPAL TAXA	COUNT	FREQ.	95%	CI	CONC.	INF.
PINACEAE	PINUS	200	33.44%	29	37	115019	978.1
PINACEAE	PINUS HAPL	16	2.67%	1	4	9202	78.7
PINACEAE	PINUS DIPL	16	2.67%	1	4	9202	78.7
PINACEAE	PICEA	52	8.69%	6	11	29905	254.6
PINACEAE	ABIES	54	9.03%	6	11	31055	264.4
PINACEAE	LARIX/PSEU	5	.83%	0	1	2875	24.9
POLYGONACEAE	POLYGON ALA	1	.16%	0	0	575	5.3
RANUNCULACEAE	THALICTRUM	10	1.67%	0	3	5751	49.3
SAXIFRAGACEAE	SAXIFRAGA	1	.16%	0	0	575	5.3
CUPRESSACEAE	JUNIPERUS	2	.33%	0	1	1150	10.2
BETULACEAE	BETULA	5	.83%	0	1	2875	24.9
BETULACEAE	ALNUS	192	32.1%	28	35	110418	939
GRAMINEAE	GRAMINEAE	7	1.17%	0	2	4026	34.7
CYPERACEAE	CYPERACEAE	11	1.83%	1	3	6326	54.2
COMPOSITAE	ARTEMISIA	21	3.51%	2	5	12077	103.1
COMPOSITAE	TUBULIFL H.S.	3	.5%	0	1	1725	15.1
CHENO-AM	CHENO-AM	2	.33%	0	1	1150	10.2

SUM

598#

CONTAM. COUNT: 42 #

CONCENTRATION: 343907#/CM3

INFLUX: 2923#/CM2/YR

FAMILY	EXCLUDED TAXA	COUNT	FREQ.	95%	CI
MISCEL	MONOLETE SPO	6	1.0%	0	2
MISCEL	TRILETE SPO	1	.16%	0	0
POLYPODIACEAE	DRYOPTERIS	3	.5%	0	1
POLYPODIACEAE	PTERIDIUM	6	1.0%	0	2
SELAGINELLACEAE	SELAGINELLA	2	.33%	0	1
LYCOPODIACEAE	LYCOPODIUM	4	.66%	0	1
MISCEL	INDETER.	21	3.51%	2	5
MISCEL	INDET BIS	44	7.35%	5	9
MISCEL	UNKNOWN	4	.66%	0	1

FILE: OPABIN

23 PRINCIPAL OF 33 IDENTIFIED TAXA

SAMPLE: 13 - DEPTH: 065CM - DEPOSITION RATE: 8.5E-03 CM/YR - CONTAMINANT: 24154#

COMMENT: NONE

FAMILY	PRINCIPAL TAXA	COUNT	FREQ.	95%	CI	CONC.	INF.
PINACEAE	PINUS	238	35.41%	31	39	87101	740.8
PINACEAE	PINUS HAPL	6	.89%	0	1	2196	19.1
PINACEAE	PINUS DIPL	16	2.38%	1	3	5856	50.2
PINACEAE	PICEA	80	11.9%	9	14	29278	249.3
PINACEAE	ABIES	51	7.58%	5	9	18664	159.1
PINACEAE	LARIX/PSEU	4	.59%	0	1	1464	12.9
POLYGONACEAE	POLYGON ALA	1	.14%	0	0	366	3.6
RANUNCULACEAE	THALICTRUM	4	.59%	0	1	1464	12.9
RANUNCULACEAE	CALTH PAL	1	.14%	0	0	366	3.6
SAXIFRAGACEAE	SAXIFRAGA	1	.14%	0	0	366	3.6
ROSACEAE	POTENTILLA	1	.14%	0	0	366	3.6
CUPRESSACEAE	JUNIPERUS	3	.44%	0	1	1098	9.8
BETULACEAE	BETULA	5	.74%	0	1	1830	16
BETULACEAE	ALNUS	205	30.5%	27	34	75024	638.2
SALICACEAE	SALIX	2	.29%	0	1	732	6.7
GRAMINEAE	GRAMINEAE	2	.29%	0	1	732	6.7
CYPERACEAE	CYPERACEAE	13	1.93%	1	3	4758	40.9
COMPOSITAE	ARTEMISIA	20	2.97%	1	4	7319	62.7
COMPOSITAE	TUBULIFL H.S.	9	1.33%	0	2	3294	28.4
COMPOSITAE	AMBROSIA	4	.59%	0	1	1464	12.9
CHENO-AM	CHENO-AM	3	.44%	0	1	1098	9.8
VALERIANACEAE	VALERIANA	2	.29%	0	1	732	6.7
ERICALES	ERICALES	1	.14%	0	0	366	3.6

SUM

672#

CONTAM. COUNT: 66 #

CONCENTRATION: 245932#/CM3

INFLUX: 2090#/CM2/YR

FAMILY	EXCLUDED TAXA	COUNT	FREQ.	95%	CI
MISCEL	MONOLETE SPO	1	.14%	0	0
MISCEL	TRILETE SPO	2	.29%	0	1
POLYPODIACEAE	DRYOPTERIS	6	.89%	0	1
POLYPODIACEAE	ATHYRIUM	3	.44%	0	1
POLYPODIACEAE	PTERIDIUM	4	.59%	0	1
SELAGINELLACEAE	SELAGINELLA	1	.14%	0	0
LYCOPODIACEAE	LYCOPODIUM	1	.14%	0	0
MISCEL	INDETER.	14	2.08%	1	3
MISCEL	INDET BIS	55	8.18%	6	10
MISCEL	UNKNOWN	4	.59%	0	1

FILE: OPABIN

21 PRINCIPAL OF 31 IDENTIFIED TAXA

SAMPLE: 12 - DEPTH: 060CM - DEPOSITION RATE: 8.5E-03 CM/YR - CONTAMINANT: 24154#

COMMENT: NONE

FAMILY	PRINCIPAL TAXA	COUNT	FREQ.	95%	CI	CONC.	INF.
PINACEAE	PINUS	207	35.14%	31	39	94337	802.3
PINACEAE	PINUS HAPL	5	.84%	0	1	2279	19.8
PINACEAE	PINUS DIPL	25	4.24%	2	6	11393	97.3
PINACEAE	PICEA	67	11.37%	9	14	30534	260
PINACEAE	ABIES	44	7.47%	5	9	20052	170.9
PINACEAE	TSUGA HET	1	.16%	0	0	456	4.3
PINACEAE	LARIX/PSEU	4	.67%	0	1	1823	15.9
POLYGONACEAE	OXYRIA	1	.16%	0	0	456	4.3
RANUNCULACEAE	THALICTRUM	2	.33%	0	1	911	8.2
SAXIFRAGACEAE	SAXIFRAGA	1	.16%	0	0	456	4.3
CUPRESSACEAE	JUNIPERUS	3	.5%	0	1	1367	12.1
BETULACEAE	BETULA	1	.16%	0	0	456	4.3
BETULACEAE	ALNUS	185	31.4%	27	35	84311	717.1
SALICACEAE	SALIX	3	.5%	0	1	1367	12.1
GRAMINEAE	GRAMINEAE	4	.67%	0	1	1823	15.9
CYPERACEAE	CYPERACEAE	16	.71%	1	4	7292	62.4
COMPOSITAE	ARTEMISIA	10	.65%	0	3	4557	39.2
COMPOSITAE	TUBULIFL H.S.	2	.33%	0	1	911	8.2
CHENO-AM	CHENO-AM	4	.67%	0	1	1823	15.9
CORNACEAE	CORNUS CAN	2	.33%	0	1	911	8.2
LEGUMINOSAE	TRIFOLIUM	2	.33%	0	1	911	8.2

SUM	589#
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CONTAM. COUNT: 53 #

CONCENTRATION: 268428#/CM3

INFLUX: 2282#/CM2/YR

FAMILY	EXCLUDED TAXA	COUNT	FREQ.	95%	CI
MISCEL	MONOLETE SPO	1	.16%	0	0
MISCEL	TRILETE SPO	2	.33%	0	1
POLYPODIACEAE	ATHYRIUM	2	.33%	0	1
POLYPODIACEAE	DRYOPTERIS	2	.33%	0	1
POLYPODIACEAE	PTERIDIUM	1	.16%	0	0
SELAGINELLACEAE	SELAGINELLA	1	.16%	0	0
LYCOPODIACEAE	LYCOPODIUM	2	.33%	0	1
MISCEL	INDETER.	17	2.88%	1	4
MISCEL	UNKNOWN	5	.84%	0	1
MISCEL	INDET BIS	45	7.64%	5	10

FILE: OPABIN

17 PRINCIPAL OF 26 IDENTIFIED TAXA

SAMPLE: 11 - DEPTH: 055CM - DEPOSITION RATE: 8.5E-03 CM/YR - CONTAMINANT: 24154#

COMMENT: NONE

FAMILY	PRINCIPAL TAXA	COUNT	FREQ.	95%	CI	CONC.	INF.
PINACEAE	PINUS	250	39.06%	35	42	120770	1027
PINACEAE	PINUS HAPL	6	.93%	0	2	2898	25.1
PINACEAE	PINUS DIPL	24	3.75%	2	5	11594	99
PINACEAE	PICEA	59	9.21%	7	11	28502	242.7
PINACEAE	ABIES	43	6.71%	5	8	20772	177
PINACEAE	LARIX/PSEU	3	.46%	0	1	1449	12.8
RANUNCULACEAE	THALICTRUM	4	.62%	0	1	1932	16.9
SAXIFRAGACEAE	SAXIFRAGA	1	.15%	0	0	483	4.6
CUPRESSACEAE	JUNIPERUS	3	.46%	0	1	1449	12.8
BETULACEAE	ALNUS	187	29.21%	25	32	90336	768.3
SALICACEAE	SALIX	2	.31%	0	1	966	8.7
GRAMINEAE	GRAMINEAE	12	1.87%	1	3	5797	49.7
CYPERACEAE	CYPERACEAE	17	2.65%	1	4	8212	70.3
COMPOSITAE	ARTEMISIA	20	3.12%	2	4	9662	82.6
COMPOSITAE	TUBULIFL H.S.	2	.31%	0	1	966	8.7
CHENO-AM	CHENO-AM	5	.78%	0	1	2415	21
ERICALES	ERICALES	2	.31%	0	1	966	8.7

SUM

640#

CONTAM. COUNT: 50 #

CONCENTRATION: 309171#/CM3

INFLUX: 2628#/CM2/YR

FAMILY	EXCLUDED TAXA	COUNT	FREQ.	95%	CI
MISCEL	MONOLETE SPO	2	.31%	0	1
MISCEL	TRILETE SPO	1	.15%	0	0
POLYPODIACEAE	DRYOPTERIS	13	2.03%	1	3
POLYPODIACEAE	ATHYRIUM	1	.15%	0	0
POLYPODIACEAE	PTERIDIUM	5	.78%	0	1
LYCOPODIACEAE	LYCOPODIUM	1	.15%	0	0
MISCEL	INDETER.	17	2.65%	1	4
MISCEL	UNKNOWN	2	.31%	0	1
MISCEL	INDET BIS	37	5.78%	4	7

FILE: OPABIN

19 PRINCIPAL OF 27 IDENTIFIED TAXA

SAMPLE: 10 - DEPTH: 050CM - DEPOSITION RATE: 8.5E-03 CM/YR - CONTAMINANT: 24154#

COMMENT: NONE

FAMILY	PRINCIPAL TAXA	COUNT	FREQ.	95% CI	CONC.	INF.
PINACEAE	PINUS	250	41.94%	38	45	125802 1069.8
PINACEAE	PINUS HAPL	6	1.0%	0	2	3019 26.1
PINACEAE	PINUS DIPL	16	2.68%	1	4	8051 68.9
PINACEAE	PICEA	71	11.91%	9	14	35728 304.1
PINACEAE	ABIES	43	7.21%	5	9	21638 184.4
PINACEAE	LARIX/PSEU	2	.33%	0	1	1006 9
RANUNCULACEAE	THALICTRUM	6	1.0%	0	2	3019 26.1
SAXIFRAGACEAE	SAXIFRAGA	1	.16%	0	0	503 4.7
ROSACEAE	DRYAS	1	.16%	0	0	503 4.7
ROSACEAE	POTENTILLA	3	.5%	0	1	1510 13.3
BETULACEAE	BETULA	8	1.34%	0	2	4026 34.7
BETULACEAE	ALNUS	142	23.82%	20	27	71456 607.8
SALICACEAE	SALIX	1	.16%	0	0	503 4.7
GRAMINEAE	GRAMINEAE	9	1.51%	0	2	4529 38.9
CYPERACEAE	CYPERACEAE	9	1.51%	0	2	4529 38.9
COMPOSITAE	ARTEMISIA	19	3.18%	2	4	9561 81.7
COMPOSITAE	TUBULIFL H.S.	5	.83%	0	1	2516 21.8
COMPOSITAE	AMBROSIA	1	.16%	0	0	503 4.7
CHENO-AM	CHENO-AM	3	.5%	0	1	1510 13.3

SUM

596#

CONTAM. COUNT: 48 #

CONCENTRATION: 299912#/CM3

INFLUX: 2549#/CM2/YR

FAMILY	EXCLUDED TAXA	COUNT	FREQ.	95%	CI
MISCEL	MONOLETE SPO	3	.5%	0	1
MISCEL	TRILETE SPO	2	.33%	0	1
POLYPODIACEAE	DRYOPTERIS	6	1.0%	0	2
SELAGINELLACEAE	SELAGINELLA	1	.16%	0	0
LYCOPODIACEAE	LYCOPODIUM	1	.16%	0	0
MISCEL	INDETER.	16	2.68%	1	4
MISCEL	UNKNOWN	4	.67%	0	1
MISCEL	INDET BIS	46	7.71%	5	10

FILE: OPABIN

20 PRINCIPAL OF 29 IDENTIFIED TAXA

SAMPLE: 9 - DEPTH: 045CM - DEPOSITION RATE: 8.5E-03 CM/YR - CONTAMINANT: 24154#

COMMENT: BELOW BRIDGE RIVER TEPHRA

FAMILY	PRINCIPAL TAXA	COUNT	FREQ.	95%	CI	CONC.	INF.
PINACEAE	PINUS	30	48.78%	44	52	90056	765.9
PINACEAE	PINUS HAPL	3	.48%	0	1	895	8.1
PINACEAE	PINUS DIPL	22	3.55%	2	5	6560	56.2
PINACEAE	PICEA	54	8.56%	6	11	15804	134.8
PINACEAE	ABIES	30	4.84%	3	6	8946	76.5
PINACEAE	TSUGA HET	5	.8%	0	1	1491	13.1
PINACEAE	LARIX/PSEU	7	1.13%	0	2	2087	18.2
POLYGONACEAE	OXYRIA	1	.16%	0	0	298	3
RANUNCULACEAE	THALICTRUM	4	.64%	0	1	1193	10.6
BETULACEAE	BETULA	2	.32%	0	1	596	5.5
BETULACEAE	ALNUS	144	23.26	20	26	42940	365.4
SALICACEAE	SALIX	1	.16%	0	0	298	3
GRAMINEAE	GRAMINEAE	11	1.77%	0	3	3280	28.3
CYPERACEAE	CYPERACEAE	11	1.77%	0	3	3280	28.3
COMPOSITAE	ARTEMISIA	14	2.26%	1	3	4175	35.9
COMPOSITAE	TUBULIFL H.S.	2	.32%	0	1	596	5.5
COMPOSITAE	AMBROSIA	1	.16%	0	0	298	3
CHENO-AM	CHENO-AM	2	.32%	0	1	596	5.5
VALERIANACEAE	VALERIANA	2	.32%	0	1	596	5.5
ERICALES	ERICALES	2	.32%	0	1	596	5.5

SUM

619#

CONTAM. COUNT: 81 #

CONCENTRATION: 184584#/CM3

INFLUX: 1569#/CM2/YR

FAMILY	EXCLUDED TAXA	COUNT	FREQ.	95%	CI
MISCEL	TRILETE SPO	1	.16%	0	0
POLYPODIACEAE	DRYOPTERIS	11	1.77%	0	3
POLYPODIACEAE	ATHYRIUM	1	.16%	0	0
POLYPODIACEAE	PTERIDIUM	2	.32%	0	1
SELAGINELLACEAE	SELAGINELLA	1	.16%	0	0
LYCOPODIACEAE	LYCOPODIUM	2	.32%	0	1
MISCEL	INDETER.	16	2.58%	1	4
MISCEL	UNKNOWN	4	.64%	0	1
MISCEL	INDET BIS	43	6.94%	5	9

FILE: OPABIN

20 PRINCIPAL OF 30 IDENTIFIED TAXA

SAMPLE: 8 - DEPTH: 040CM - DEPOSITION RATE: .0183 CM/YR - CONTAMINANT: 24154#

COMMENT: ABOVE BRIDGE RIVER TEPHRA

FAMILY	PRINCIPAL TAXA	COUNT	FREQ.	95%	CI	CONC.	INF.
PINACEAE	PINUS	345	52.59%	48	56	112610	2061.2
PINACEAE	PINUS HAPL	5	.76%	0	1	1632	30.3
PINACEAE	PINUS DIPL	29	4.42%	3	6	9466	173.7
PINACEAE	PICEA	42	6.4%	4	8	13709	251.3
PINACEAE	ABIES	17	2.59%	1	4	5549	102
PINACEAE	TSUGA HET	7	1.06%	0	2	2285	42.3
PINACEAE	LARIX/PSEU	4	.6%	0	1	1306	24.3
RANUNCULACEAE	THALICTRUM	2	.3%	0	1	653	12.4
SAXIFRAGACEAE	SAXIFRAGA	4	.6%	0	1	1306	24.3
ROSACEAE	DRYAS	1	.15%	0	0	326	6.4
CUPRESSACEAE	JUNIPERUS	2	.3%	0	1	653	12.4
BETULACEAE	BETULA	1	.15%	0	0	326	6.4
BETULACEAE	ALNUS	159	24.23%	21	27	51898	950.2
SALICACEAE	SALIX	1	.15%	0	0	326	6.4
GRAMINEAE	GRAMINEAE	10	1.52%	0	2	3264	60.2
CYPERACEAE	CYPERACEAE	12	1.82%	1	3	3917	72.1
COMPOSITAE	ARTEMISIA	10	1.52%	0	2	3264	60.2
COMPOSITAE	TUBULIFL H.S.	3	.45%	0	1	979	18.4
CHENO-AM	CHENO-AM	1	.15%	0	0	326	6.4
ERICALES	ERICALES	1	.15%	0	0	326	6.4

SUM

656#

CONTAM. COUNT: 74 #

CONCENTRATION: 214122#/CM3

INFLUX: 3918#/CM2/YR

FAMILY	EXCLUDED TAXA	COUNT	FREQ.	95%	CI
MISCEL	MONOLETE SPO	1	.15%	0	0
MISCEL	INAPERTURATE SPO	2	.3%	0	1
POLYPODIACEAE	DRYOPTERIS	9	1.37%	0	2
LYCOPODIACEAE	LYCOPODIUM	2	.3%	0	1
POLYPODIACEAE	PTERIDIUM	3	.45%	0	1
POLYPODIACEAE	ATHYRIUM	3	.45%	0	1
SELAGINELLACEAE	SELAGINELLA	1	.15%	0	0
MISCEL	INDETER.	15	2.28%	1	3
MISCEL	UNKNOWN	2	.3%	0	1
MISCEL	INDET BIS	41	6.25%	4	8

FILE: OPABIN

19 PRINCIPAL OF 26 IDENTIFIED TAXA

SAMPLE: 7 - DEPTH: 035CM - DEPOSITION RATE: .0183 CM/YR - CONTAMINANT: 24154#

COMMENT: NONE

FAMILY	PRINCIPAL TAXA	COUNT	FREQ.	95%	CI	CONC.	INF.
PINACEAE	PINUS	331	56.48%	52	60	83281	1524.5
PINACEAE	PINUS HAPL	4	.68%	0	1	1006	18.9
PINACEAE	PINUS DIPL	26	4.43%	3	6	6542	120.2
PINACEAE	PICEA	32	5.46%	3	7	8051	147.8
PINACEAE	ABIES	14	2.38%	1	3	3522	64.9
PINACEAE	TSUGA HET	9	1.53%	0	2	2264	41.9
PINACEAE	LARIX/PSEU	2	.34%	0	1	503	9.7
POLYGONACEAE	POLYGON ALA	1	.17%	0	0	252	5.1
SAXIFRAGACEAE	SAXIFRAGA	3	.51%	0	1	755	14.3
BETULACEAE	ALNUS	114	19.45%	16	22	28683	525.3
BETULACEAE	BETULA	1	.17%	0	0	252	5.1
GRAMINEAE	GRAMINEAE	11	1.87%	1	3	2768	51.1
CYPERACEAE	CYPERACEAE	22	3.75%	2	5	5535	101.7
COMPOSITAE	ARTEMISIA	4	.68%	0	1	1006	18.9
COMPOSITAE	TUBULIFL H.S.	4	.68%	0	1	1006	18.9
COMPOSITAE	AMBROSIA	2	.34%	0	1	503	9.7
CHENO-AM	CHENO-AM	4	.68%	0	1	1006	18.9
CARYOPHYLLACEAE	CARYOPHYLLACEAE	1	.17%	0	0	252	5.1
ERICALES	ERICALES	1	.17%	0	0	252	5.1

SUM 586#

CONTAM. COUNT: 96 #

CONCENTRATION: 147440#/CM3

INFLUX: 2698#/CM2/YR

FAMILY	EXCLUDED TAXA	COUNT	FREQ.	95%	CI
MISCEL	MONOLETE SPO	2	.34%	0	1
MISCEL	TRILETE SPO	5	.85%	0	1
POLYPODIACEAE	DRYOPTERIS	4	.68%	0	1
SELAGINELLACEAE	SELAGINELLA	1	.17%	0	0
MISCEL	INDETER.	22	3.75%	2	5
MISCEL	UNKNOWN	3	.51%	0	1
MISCEL	INDET BIS	31	5.29%	3	7

FILE: OPABIN

17 PRINCIPAL OF 25 IDENTIFIED TAXA

SAMPLE: 6 - DEPTH: 030CM - DEPOSITION RATE: .0183 CM/YR - CONTAMINANT: 24154#

COMMENT: NONE

FAMILY	PRINCIPAL TAXA	COUNT	FREQ.	95%	CI	CONC.	INF.
PINACEAE	PINUS	300	51.63%	47	55	154174	2821.8
PINACEAE	PINUS HAPL	7	1.2%	0	2	3597	66.3
PINACEAE	PINUS DIPL	26	4.47%	3	6	13362	245
PINACEAE	PICEA	54	9.29%	7	11	27751	508.3
PINACEAE	ABIES	20	3.44%	2	5	10278	188.5
PINACEAE	TSUGA HET	9	1.54%	0	2	4625	85.1
PINACEAE	LARIX/PSEU	3	.51%	0	1	1542	28.7
CUPRESSACEAE	JUNIPERUS	5	.86%	0	1	2570	47.5
BETULACEAE	BETULA	2	.34%	0	1	1028	19.3
BETULACEAE	ALNUS	115	19.79%	16	23	59100	1082
SALICACEAE	SALIX	2	.34%	0	1	1028	19.3
GRAMINEAE	GRAMINEAE	6	1.03%	0	2	3083	56.9
CYPERACEAE	CYPERACEAE	18	3.09%	1	4	9250	169.7
COMPOSITAE	ARTEMISIA	11	1.89%	1	3	5653	103.9
COMPOSITAE	TUBULIFL H.S.	1	.17%	0	0	514	9.9
COMPOSITAE	AMBROSIA	1	.17%	0	0	514	9.9
PRIMULACEAE	ANDROSACE	1	.17%	0	0	514	9.9

SUM

581#

CONTAM. COUNT: 47 #

CONCENTRATION: 298585#/CM3

INFLUX: 5464#/CM2/YR

FAMILY	EXCLUDED TAXA	COUNT	FREQ.	95%	CI
MISCEL	MONOLETE SPO	3	.51%	0	1
MISCEL	TRILETE SPO	2	.34%	0	1
MISCEL	INAPERTURATE SPO	1	.17%	0	0
POLYPODIACEAE	DRYOPTERIS	3	.51%	0	1
POLYPODIACEAE	ATHYRIUM	1	.17%	0	0
MISCEL	INDETER.	18	3.09%	1	4
MISCEL	UNKNOWN	3	.51%	0	1
MISCEL	INDET BIS	32	5.5%	3	7

FILE: OPABIN

21 PRINCIPAL OF 29 IDENTIFIED TAXA

SAMPLE: 5 - DEPTH: 025CM - DEPOSITION RATE: .0183 CM/YR - CONTAMINANT: 24154#

COMMENT:NONE

FAMILY	PRINCIPAL TAXA	COUNT	FREQ.	95%	CI	CONC.	INF.
PINACEAE	PINUS	293	51.76%	47	55	110580	2024.1
PINACEAE	PINUS HAPL	9	1.59%	0	2	3397	62.6
PINACEAE	PINUS DIPL	30	5.3%	3	7	11322	207.6
PINACEAE	PICEA	35	6.18%	4	8	13209	242.2
PINACEAE	ABIES	11	1.94%	1	3	4151	76.4
PINACEAE	TSUGA HET	11	1.94%	1	3	4151	76.4
PINACEAE	LARIX/PSEU	5	.88%	0	2	1887	35
POLYGONACEAE	OXYRIA	1	.17%	0	0	377	7.3
RANUNCULACEAE	THALICTRUM	2	.35%	0	1	755	14.3
BETULACEAE	BETULA	4	.7%	0	1	1510	28.1
BETULACEAE	ALNUS	115	20.31%	17	23	43402	794.7
BETULACEAE	CORYLUS	1	.17%	0	0	377	7.3
SALICACEAE	SALIX	2	.35%	0	1	755	14.3
GRAMINEAE	GRAMINEAE	13	2.29%	1	3	4906	90.2
CYPERACEAE	CYPERACEAE	18	3.18%	2	4	6793	124.8
COMPOSITAE	ARTEMISIA	11	1.94%	1	3	4151	76.4
COMPOSITAE	TUBULIFL H.S.	1	.17%	0	0	377	7.3
COMPOSITAE	AMBROSIA	1	.17%	0	0	377	7.3
CHENO-AM	CHENO-AM	1	.17%	0	0	377	7.3
PRIMULACEAE	ANDROSACE	1	.17%	0	0	377	7.3
ERICALES	ERICALES	1	.17%	0	0	377	7.3

SUM 566#

CONTAM. COUNT: 64 #

CONCENTRATION: 213612#/CM3

INFLUX: 3909#/CM2/YR

FAMILY	EXCLUDED TAXA	COUNT	FREQ.	95%	CI
MISCEL	MONOLETE SPO	6	1.06%	0	2
MISCLE	TRILETE SPO	1	.17%	0	0
POLYPODIACEAE	DRYOPTERIS	9	1.59%	0	2
POLYPODIACEAE	ATHYRIUM	1	.17%	0	0
LYCOPODIACEAE	LYCOPODIUM	1	.17%	0	0
MISCEL	INDETER.	15	2.65%	1	4
MISCEL	UNKNOWN	4	.7%	0	1
MISCEL	INDET BIS	39	6.89%	5	9

FILE: OPABIN

17 PRINCIPAL OF 23 IDENTIFIED TAXA

SAMPLE: 4 - DEPTH: 020CM - DEPOSITION RATE: .0183 CM/YR - CONTAMINANT: 24154#

COMMENT: NONE

FAMILY	PRINCIPAL TAXA	COUNT	FREQ.	95%	CI	CONC.	INF.
PINACEAE	PINUS	251	49.4%	45	53	37656	689.6
PINACEAE	PINUS HAPL	5	.98%	0	2	750	14.2
PINACEAE	PINUS DIPL	25	4.92%	3	7	3751	69.1
PINACEAE	PICEA	19	3.74%	2	5	2850	52.6
PINACEAE	ABIES	5	.98%	0	2	750	14.2
PINACEAE	TSUGA HET	10	1.96%	1	3	1500	27.9
PINACEAE	LARIX/PSEU	4	.78%	0	2	600	11.4
RANUNCULACEAE	THALICRUM	2	.39%	0	1	300	5.9
CUPRESSACEAE	JUNIPERUS	3	.59%	0	1	450	8.7
BETULACEAE	ALNUS	124	24.4%	20	28	18603	340.9
SALICACEAE	SALIX	6	1.18%	0	2	900	16.9
GRAMINEAE	GRAMINEAE	7	1.37%	0	2	1050	19.7
CYPERACEAE	CYPERACEAE	33	6.49%	4	8	4951	91.1
COMPOSITAE	ARTEMISIA	6	1.18%	0	2	900	16.9
COMPOSITAE	TUBULIFL H.S.	1	.19%	0	1	150	3.2
CHENO-AM	CHENO-AM	4	.78%	0	2	600	11.4
PRIMULACEAE	ANDROSACE	3	.59%	0	1	450	8.7

SUM

508#

CONTAM. COUNT: 161 #

CONCENTRATION: 76213#/CM3

INFLUX: 1395#/CM2/YR

FAMILY	EXCLUDED TAXA	COUNT	FREQ.	95%	CI
MISCEL	MONOLETE SPO	2	.39%	0	1
MISCEL	TRILETE SPO	4	.78%	0	2
POLYPODIACEAE	DRYOPTERIS	12	2.36%	1	4
MISCEL	INDETER.	28	5.51%	3	7
MISCEL	UNKNOWN	2	.39%	0	1
MISCEL	INDET BIS	47	9.25%	7	12

FILE: OPABIN

18 PRINCIPAL OF 24 IDENTIFIED TAXA

SAMPLE: 3 - DEPTH: 015CM - DEPOSITION RATE: .0183 CM/YR - CONTAMINANT: 24154#

COMMENT: NONE

FAMILY	PRINCIPAL TAXA	COUNT	FREQ.	95%	CI	CONC.	INF.
PINACEAE	PINUS	341	59.4%	55	63	128696	2355.6
PINACEAE	PINUS HAPL	4	.69%	0	1	1510	28.1
PINACEAE	PINUS DIPL	28	4.87%	3	6	10567	193.8
PINACEAE	PICEA	20	3.48%	2	5	7548	138.6
PINACEAE	ABIES	12	2.09%	1	3	4529	83.3
PINACEAE	TSUGA HET	10	1.74%	0	3	3774	69.5
PINACEAE	LARIX/PSEU	5	.87%	0	2	1887	35
RANUNCULACEAE	THALICTRUM	2	.34%	0	1	755	14.3
CUPRESSACEAE	JUNIPERUS	1	.17%	0	0	377	7.3
BETULACEAE	ALNUS	99	17.24%	14	20	37363	684.2
SALICACEAE	SALIX	2	.34%	0	1	755	14.3
GRAMINEAE	GRAMINEAE	6	1.04%	0	2	2264	41.9
CYPERACEAE	CYPERACEAE	31	5.4%	3	7	11700	214.6
COMPOSITAE	ARTEMISIA	6	1.04%	0	2	2264	41.9
COMPOSITAE	TUBULIFL H.S.	1	.17%	0	0	377	7.3
COMPOSITAE	AMBROSIA	1	.17%	0	0	377	7.3
CHENO-AM	CHENO-AM	4	.69%	0	1	1510	28.1
ERICALES	ERICALES	1	.17%	0	0	377	7.3

SUM

574#

CONTAM. COUNT: 64 #

CONCENTRATION: 216631#/CM3

INFLUX: 3964#/CM2/YR

FAMILY	EXCLUDED TAXA	COUNT	FREQ.	95%	CI
POLYPODIACEAE	DRYOPTERIS	7	1.21%	0	2
MISCEL	TRILETE SPO	3	.52%	0	1
MISCEL	MONOLETE SPO	3	.52%	0	1
MISCEL	INDETER.	13	2.26%	1	3
MISCEL	UNKNOWN	5	.87%	0	2
MISCEL	INDET BIS	59	10.27%	8	13

FILE: OPABIN

19 PRINCIPAL OF 22 IDENTIFIED TAXA

SAMPLE: 2 - DEPTH: 005CM - DEPOSITION RATE: .0183 CM/YR - CONTAMINANT: 24154#

COMMENT: NONE

FAMILY	PRINCIPAL TAXA	COUNT	FREQ.	95%	CI	CONC.	INF.
PINACEAE	PINUS	314	56.47%	52	60	92492	1693.1
PINACEAE	PINUS HAPL	6	1.07%	0	2	1767	32.8
PINACEAE	PINUS DIPL	26	4.67%	3	6	7659	140.6
PINACEAE	PICEA	40	7.19%	5	9	11782	216.1
PINACEAE	ABIES	12	2.15%	1	3	3535	65.1
PINACEAE	TSUGA HET	7	1.25%	0	2	2062	38.2
PINACEAE	LARIX/PSEU	2	.35%	0	1	589	11.2
CURPESSACEAE	JUNIPERUS	2	.35%	0	1	589	11.2
BETULACEAE	ALNUS	97	17.44%	14	20	28572	523.3
BETULACEAE	CORYLUS	2	.35%	0	1	589	11.2
SALICACEAE	SALIX	4	.71%	0	1	1178	22
GRAMINEAE	GRAMINEAE	6	1.07%	0	2	1767	32.8
CYPERACEAE	CYPERACEAE	24	4.31%	2	6	7069	129.8
COMPOSITAE	ARTEMISIA	6	1.07%	0	2	1767	32.8
COMPOSITAE	TUBULIFL H.S.	2	.35%	0	1	589	11.2
CHENO-AM	CHENO-AM	2	.35%	0	1	589	11.2
CARYOPHYLLACEAE	CARYOPHYLLACE	1	.17%	0	1	295	5.8
PRIMULACEAE	ANDROSACE	2	.35%	0	1	589	11.2
ERICALES	ERICALES	1	.17%	0	1	295	5.8

SUM 556#

CONTAM. COUNT: 82 #

CONCENTRATION: 163776#/CM3

INFLUX: 2997#/CM2/YR

FAMILY	EXCLUDED TAXA	COUNT	FREQ.	95%	CI
POLYPODIACEAE	DRYOPTERIS	11	1.97%	1	3
LYCOPODIACEAE	LYCOPODIUM	3	.53%	0	1
MISCEL	TRILETE SPO	2	.35%	0	1
MISCEL	INAPERTURATE SPO	2	.35%	0	1
MISCEL	INDETER.	17	3.05%	1	4
MISCEL	UNKNOWN	4	.71%	0	1
MISCEL	INDET BIS	58	10.43%	8	13

FILE: OPABIN

20 PRINCIPAL OF 28 IDENTIFIED TAXA

SAMPLE: 1 - DEPTH: 005CM - DEPOSITION RATE: .0183 CM/YR - CONTAMINANT: 24154#

COMMENT: CORE TOP

FAMILY	PRINCIPAL TAXA	COUNT	FREQ.	95%	CI	CONC.	INF.
PINACEAE	PINUS	260	47.27%	43	51	98126	1796.2
PINACEAE	PINUS HAPL	3	.54%	0	1	1132	21.2
PINACEAE	PINUS DIPL	17	3.09%	1	4	6416	117.9
PINACEAE	PICEA	25	4.54%	3	6	9435	173.1
PINACEAE	ABIES	8	1.45%	0	2	3019	55.7
PINACEAE	LARIX/PSEU	3	.54%	0	1	1132	21.2
PINACEAE	TSUGA HET	12	2.18%	1	3	4529	83.3
RANUNCULACEAE	THALICTRUM	4	.72%	0	1	1510	28.1
CUPRESSACEAE	JUNIPERUS	2	.36%	0	1	755	14.3
BETULACEAE	ALNUS	164	29.81%	26	33	61895	1133.1
BETULACEAE	BETULA	3	.54%	0	1	1132	21.2
SALICACEAE	SALIX	2	.36%	0	1	755	14.3
GRAMINEAE	GRAMINEAE	1	.18%	0	1	377	7.3
CYPERACEAE	CYPERACEAE	27	4.9%	3	7	10190	186.9
COMPOSITAE	AMBROSIA	1	.18%	0	1	377	7.3
COMPOSITAE	TUBULIFL H.S.	2	.36%	0	1	755	14.3
COMPOSITAE	ARTEMISIA	13	2.36%	1	4	4906	90.2
CHENO-AM	CHENO-AM	1	.18%	0	1	377	7.3
CHENO-AM	SARCOBATUS	1	.18%	0	1	377	7.3
PRIMULACEAE	ANDROSACE	1	.18%	0	1	377	7.3

SUM

550#

CONTAM. COUNT: 64 #

CONCENTRATION: 207573#/CM3

INFLUX: 3799#/CM2/YR

FAMILY	EXCLUDED TAXA	COUNT	FREQ.	95%	CI
POLYPODIACEAE	DRYOPTERIS	11	1.99%	1	3
LYCOPODIACEAE	LYCOPODIUM	1	.18%	0	1
MISCEL	TRILETE SPO	4	.72%	0	1
MISCEL	MONOLETE SPO	2	.36%	0	1
MISCEL	INAPERTURATE SPO	5	.9%	0	2
MISCEL	INDETER.	27	4.9%	3	7
MISCEL	UNKNOWN	6	1.09%	0	2
MISCEL	INDET BIS	58	10.54%	8	13